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Biophysical and Socioeconomic Impacts of Farmer Managed Natural Regeneration in Burkina Faso

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BIOPHYSICAL AND SOCIOECONOMIC IMPACTS OF FARMER MANAGED NATURAL REGENERATION IN BURKINA FASO

BY

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CONTENTS

ABBREVIATIONS

ANOVA - Analysis of Variance

BS - Base Saturation

CEC - Cation-Exchange Capacity

FAO - Food and Agriculture Organization of the United Nations

FMNR - Farmer Managed Natural Regeneration

NGO - Non-Governmental Organization

pH - Potential of Hydrogen

TEBC - Total Exchangeable Base Cations

UN – United Nations

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ABSTRACT

BIOPHYSICAL AND SOCIOECONOMIC IMPACTS OF FARMER MANAGED NATURAL REGENERATION IN BURKINA FASO

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Human actions such as overgrazing, the development of cities at the expense of forests, high intensity and poor agricultural management, and so forth, reduce the resources available for future generations. Because Earth has limited resources, it is important to judiciously use and manage natural resources. Human actions towards nature are the focus of my research in Africa. Increased demands for grazing, agriculture, and ecosystem services led some farmers in developing countries to use unsustainable practices, which may lead to low incomes and poor food nutrition for households. Farmer managed natural regeneration (FMNR) may be a solution to these issues. FMNR is a land restoration technique that consists of the protection and management of naturally regenerated trees to increase the value and quantity of woody vegetation in croplands. This increases food and wood production, farm income, and makes farmers more resilient to weather extremes. My research examines FMNR impacts in the Nord Plateau Mossi of Burkina Faso, where some farmers, men and women who till the land, work on or operate farmland, or make decisions about how a particular piece of farmland is used, were able to revegetate degraded lands. Few studies, however, show the impacts of FMNR on farmers' lives. I wanted to know how FMNR affects soil productivity, household access to a variety of foods, and farmers' income. To reach my objectives, I interviewed farmers in the study area to learn their motivations for choosing whether to adopt FMNR. In addition to providing motivations, the interviews provided information about how FMNR led to changes in families' food and income. Additionally, I collected soil samples under trees and away from trees to assess their impact on soil fertility. The main findings of this research revealed that trees increased soil fertility by increasing soil carbon, organic matter, and nitrogen. Additionally, trees contribute 81 to 184 USD to household income per year. Trees also facilitates the obtaining of firewood, improves household access to a variety of foods, provides medicinal products, reduces wind speed, and keeps the soil moist. Tree leaves are used to fertilize croplands, make compost, and protect croplands from sunlight. Tree branches are used as poles for construction, wood for granaries, and fences. The findings of my research demonstrate an improvement in farmers' lives and land which, in turn, can be used to educate other farmers to adopt FMNR to restore their degraded croplands, and thus contribute to the fight against poverty and hunger in Burkina Faso.

Keywords: Farmer managed natural regeneration (FMNR), land management, sustainability, Burkina Faso.

CHAPTER 1: INTRODUCTION

Human alteration of natural resources such as oceans, landscapes, freshwaters, and so forth, as well as biogeochemical and hydrologic cycles (Kates and Parris 2003, 8064) can result in reduction or loss of certain benefits provided to humans by the natural environment. Human actions towards nature, the physical environment, are the focus of my research particularly in Africa. My research examines the impacts of farmer managed natural regeneration (FMNR), a sustainable agricultural practice, in the Nord Plateau Mossi of Burkina Faso. I wanted to know how FMNR affects soil productivity, household access to a variety of foods, and farmers' income. Farmers are men and women who till the land, work on or operate farmland, or make decisions about how a particular piece of farmland is used.

1.1 Description of the Problem

1.1.1 Background

Because of the limited resources on earth, it is important to wisely use and manage natural resources for the sake of future generations. The possible consequences of human actions on the landscape, natural resources, and opportunities available for future generations refer to the concept of sustainability (Harden 2009). Defined as "development achieved using methods that preserve the environment for future generations" (Koth 2013, 558), the modern term "sustainability" is an interdisciplinary concept that was defined in 1987 in *Our Common Future* (Mulligan 2015, 11). A model known as the three pillars of sustainability gives an overview of the issue of sustainability. The three pillars are the economy, the environment, and society (Wichaisri and Sopadang 2018, 1).

The approach that societies use to achieve sustainable development is important for humanity because the ongoing issues of poverty, hunger, disease, violence, inequality, and so forth differ from place to place. The United Nations adopted a roadmap in September 2015 titled *Transforming our World: the 2030 Agenda for Sustainable Development* (Transforming our World 2016, 26). This agenda introduced Sustainable Development Goals, to replace the Millennium Development Goals (Lim et al. 2016, 1813) that ran from 2000 to 2015. Although the Millennium Development Goals provided a framework for development, significant progress still needs to be made, especially in developing countries (United Nations 2015, 7). Pollution, climate change, poverty, and natural disasters are still affecting people repeatedly around the world. Why are the issues related to sustainability still present and growing in our societies?

An explanation to the ongoing issues might be the lack of balance between the earth and humans in the current sustainable development view. To achieve sustainable development, humans must reconsider their lifestyles with each other and with nature (Wilbanks 1994, 542). The ideal field where the studies about the relationships between humans and the environment fit is geography. “Geography would appear to be the discipline that is most readily associated with the subject area of sustainable development” (Higgitt et al. 2005, 16). Geographers have the knowledge, skills, and tools to connect humans and the environment within the temporal and spatial components of geography. Geographers and non-geographers share this perception that geography is the key component to sustainability because place matters (Bednarz 2006, 339; Liu 2011, 249). “The Environmental Protection Agency (EPA), National Council for Geographic Education (NCGE), National Research Council (NRC), The National Science Foundation (NSF), and other organizations have made calls for the inclusion of geographic theory, tools, and perspective in sustainability studies” (Bonney et al. 2014, 3). If the current thoughts in sustainability are focusing on geographers, it has not always been the case (Figure 1).

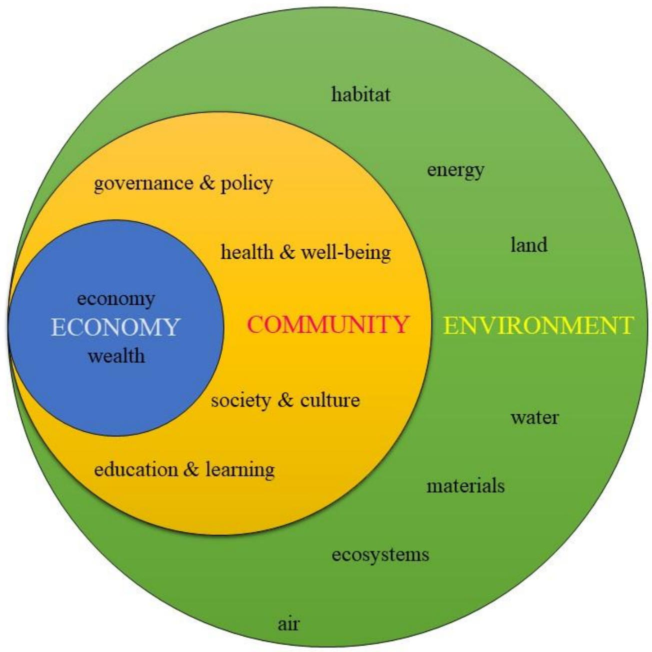

Figure 1. Sustainability general model

Source: Adapted from James Cook University 2020

The concept of sustainability rapidly caught world attention. Nonetheless, geographers were slow to embrace the key component of the issue, which is the physical environment. Most of the sustainability research in geography was in human ecology (example: Woodwell 1990), political ecology, land use, and land change. Yet, geography is one of the most effective ways to approach this concept because it provides tools that help understand how humans are constantly modifying and shaping the environment, as well as how the environment affects our decisions and thoughts. Geographers developed theories that help understand processes and relationships within the natural environment, as well as tools for data organization and information, and active knowledge of natural and social sciences. Most importantly, they teach a respect for theories from other disciplines (Kates 1987, 532). These geographical tools allow geographers to access the responses of human beings to the environmental features as element of the natural environment.

1.1.2 Environmental Issues

My research focuses on the responses of humans to the environmental features in Africa because of the increased demand in the region for grazing, agriculture, and ecosystem services, which is defined as "things that ecosystems provide that matter to people" (Millennium Ecosystem Assessment 2005, 5). In addition, population growth and the delay in technological progress make Africa a suitable area to study the responses of human to environmental patterns. Those responses led to some geographical, environmental issues that are present in the continent. Land degradation is one of them.

The U.S. Library of Congress accepted the concept of land degradation as a category within its reference system only in August 1994. Yet, there is no global agreement on its definition (Johnson and Lewis 2007, 3). Vegetation change is commonly used to evaluate land degradation (Hochstrasser et al. 2014, 15-20), with two main aspects of land degradation globally accepted. "First, there must be a substantial decrease in the biological productivity of a land system; and, second this decrease is the result of processes resulting from human activities rather than natural events" (Johnson and Lewis 2007, 3). Land degradation has been a long and ongoing environmental threat for sustaining livelihoods in many countries and is the most challenging environmental issue in drylands (Easdale 2016, 129). This issue can be explained by low average and highly variable precipitation. This high variability in precipitation is difficult for people to adapt to because of the difficulty of making assumptions regarding precipitation. Additionally, land degradation can be explained by the use of unsustainable methods to solve the economic stress and boost development in developing countries, such as overgrazing, the development of cities at the expense of forests, high intensity and poor agricultural management, and frequent land use changes (Jiang, Bamutaze, and Pilesjo 2014, 39). This led to some environmental issues and reduced soil fertility.

Inappropriate agricultural practices may lead to a reduction or depletion of soil organic matter and organic carbon (Maltas et al. 2018, 926), and to other issues. For example, population growth led to the replacement of large areas of forest in the Mount Elgon agricultural region of Uganda with agricultural fields, resulting in landslides, erosion, and stream pollution (Mugagga, Kakembo, and Buyinza 2012, 45). The extraction of charcoal, construction, and lumber exports are some factors that influenced forest degradation in Tanzania. Results included carbon storage and biodiversity declines, in addition to the decline of the number of trees per hectare, and the mean tree diameter in a given forest (Ahrends et al. 2014, 14558).

Inappropriate land management can lead to dramatic land degradation such as desertification and deforestation. Desertification is “the degradation of land in arid, semi-arid, and dry sub-humid areas. It is a gradual process of soil productivity loss and the thinning out of the vegetative cover” (UNCCD 2020). The principal causes of desertification can be found in societal changes and natural factors. Societal changes associated with desertification include increased pressure on land from growing populations, agriculture intensification, agricultural land expansion, sedentarization of nomadic people, disintegration of traditional livelihood systems, introduction of inappropriate technology, and, in general, inappropriate land management strategies (Nicholson 1998, 816; Doso 2014, 70). Rainfall characteristics, geomorphology, and soil properties define natural factors (Abu Hammad and Tumeizi 2012, 216). By adopting unsustainable actions toward the environment, destructing, and constantly reshaping the landscape to feed themselves or gain material goods, human beings are, with climatic variations, the main contributors to land degradation and desertification (US Committee on Foreign Relations 2000, 2). Additionally, "land degradation and desertification are at the same time consequences of inappropriate pressure on land and contributors to poverty and malnutrition" (Tougiani, Guero, and Rinaudo 2009, 379).

Unsustainable land management may cause important issues such as poverty and hunger, because the Earth is a closed system in terms of matter, and because of the close relationship between vegetation and other biophysical processes of the environment (Hochstrasser et al. 2014, 20). In sub-Sahara Africa, the number of undernourished people increased about 18% from 1990 to 2003 despite the resolution taken by over 180 countries worldwide in 1996 to reduce the number of undernourished people in the world (Melito 2008, 1). This increase of undernourished people in sub-Saharan Africa is because of low agricultural productivity, weak rural development, inappropriate government policy, poor health care for farmers, increases in food prices, and climate change (Melito 2008, 2). For Africa as a whole, the percentage of people affected by poverty and hunger decreased respectively from 44 in 1995-2003 to 41 in 2003-2012, and

24.6 4 in 1995-2003 to 20.6 in 2003-2012; however, the number of undernourished and poor people increased between the two periods (International Food Policy Research Institute 2015, 74). Since most people in Africa are farmers, unsustainable agricultural practices that lead to low income and poor nutrition will affect a large percent and number of people. Nevertheless, if agriculture is the key to the persistence of hunger and poverty in Africa because of poor land management and other factors, it also can be the solution for reducing poverty and hunger, if appropriate methods and techniques are used for production (Scaling up the Fight Against Poverty and Hunger in Africa 2012, 1). Agricultural solutions for reducing poverty and hunger include food aid, large commercial agriculture using the Western model, leasing or selling land to others (e.g. China, Czech Republic, Hungary, Slovakia, Bulgaria, and so forth), crop rotation, cover crops, promotion of rapid urbanization so that people can purchase their food, and land restoration techniques. One of those land restoration techniques that some have found useful especially in sub-Sahara Africa is farmer managed natural regeneration (FMNR). Could FMNR be a solution to the current problems of hunger and poverty mentioned earlier?

1.2 Framing the Problem

1.2.1 Farmer Managed Natural Regeneration

Farmer managed natural regeneration is a land restoration technique that consists of the protection and management of naturally regenerated trees to increase the value and quantity of woody vegetation on croplands. This is a regreening practice that increases food and wood production, farm income, and makes farmers more resilient to weather extremes (Reij and Winterbottom 2015, 22). Regreening is the use of agroforestry and related sustainable land management practices to restore and increase the resilience and productivity (or production per unit area) of degraded landscapes (Reij and Winterbottom 2015, 11). "In a world grappling with the challenges of food insecurity, climate change, landscape degradation, and rural poverty, regreening offers a path forward, especially in dryland areas" (Reij and Winterbottom 2015, 3).

1.2.2 Farmer Managed Natural Regeneration in Burkina Faso

This study will focus on the impacts of FMNR in the Nord Plateau Mossi (Figure 2) because, even though there is notable progress in regreening in Burkina Faso, there are few studies that show the socioeconomic (household income, access to varieties of food), and biophysical impacts (soil fertility, firewood) of FMNR on farmers' lives. Burkina Faso has fifteen ecoregions (Figure 3), the Nord Plateau Mossi being the largest. Ecoregions are "areas of relative homogeneity with respect to ecological systems involving the interrelationships of plants, animals, and their environment" (CILSS 2016, 13). The Nord Plateau Mossi straddles the Sahel and Sudan Savanna bio-climatic regions and is geographically located in seven administrative regions, but is mainly in the Centre-Nord and Nord regions. This plateau is drained by the upper reaches of the Nakambe, a temporary stream, whose source is east of Ouahigouya in the Nord region, and the Faga, a temporary tributary of the Niger River. Orthents (or lithosols) and leached tropical ferruginous soils are the main type of soils in the Nord Plateau Mossi. Overall, the northern part of the country receives less rainfall than the other parts of the country. Rainfall increases from the northern part to the southern part of the country (Gelb et al 2015, 18).

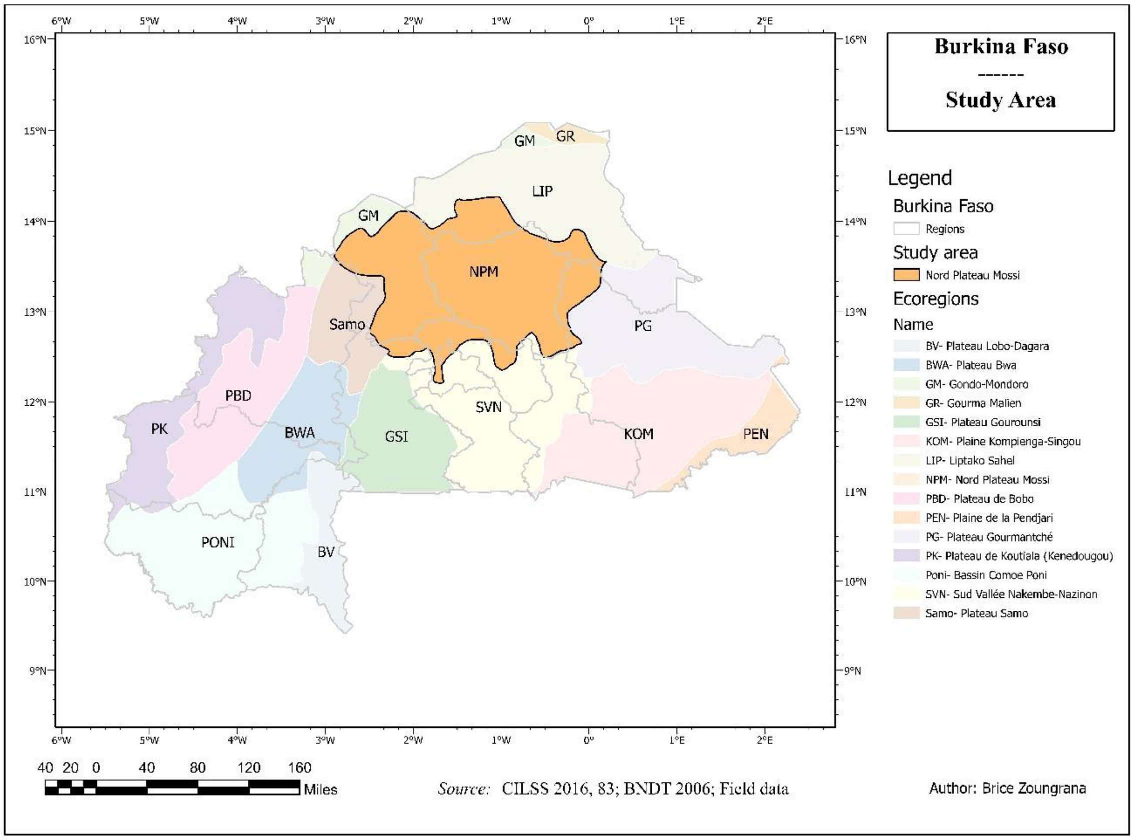

Figure 2. Study area

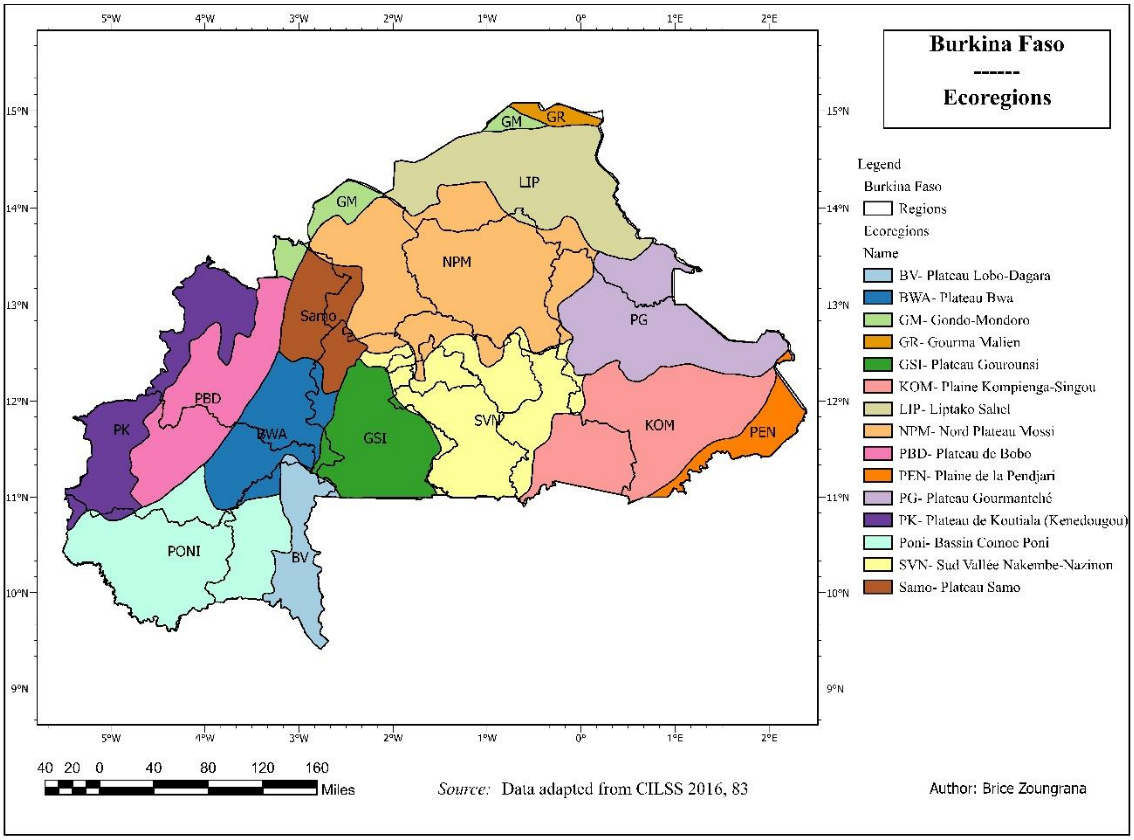

Figure 3. Burkina Faso ecoregions

The diffusion of FMNR in Burkina Faso emerged after the country suffered from a 1968-1973 drought that caused the deaths of people, animals, and trees. This drought caused a human, economic, and environmental crisis because it significantly dropped the groundwater levels, as well as yields for staple crops. It also led to a movement of people from the desiccated lands of the northern part of the country to areas with more rainfall (southern part), and to other countries such as Ivory Coast (Reij, Tappan, and Smale 2009a, 3). The central part of the country, which is the most populated region, also suffered from those movements because of increased pressure on cultivable lands by migrants, and declining rainfall. To cope with the crisis and reduce soil erosion, during the 1960s and 1970s international aid conducted two major projects to build earth bunds.

Bunds are walls of "stone or earth, built to stop an area being covered by a large amount of water" (Oxford Learner's Dictionaries, s.v "bund" [accessed June 4, 2020, https://www.oxfordlearnersdictionaries.com/us/definition/english/bund]). These projects failed because they were "conceived without the involvement of local people, however, the projects did not meet farmers' needs. Indeed, farmers failed to maintain the bunds or deliberately destroyed them, and the bunds soon disappeared" (Reij, Tappan, and Smale 2009b, 54). In addition, government projects and programs to plant millions of trees have also failed to stop erosion because of uncontrolled grazing by livestock, unsustainable use of trees for cooking and heating, and the non-involvement of farmers in those activities (Sawadogo et al. 2001, 36). "Nevertheless, compared with the early 1980s, there has been a dramatic increase in the number of trees growing on farmers' fields in part of the Yatenga region" (Sawadogo et al. 2001, 36). The focus of my research was to determine why some farmers informally supported regreening and the impacts of increased trees on those farmers' lives.

1.3 Research Question and Objectives

I am looking at the biophysical and socioeconomic impacts of farmer managed natural regeneration in the Nord Plateau Mossi of Burkina Faso, because I want to know how FMNR affects soil productivity, household access to a variety of foods, and farmers' income. If FMNR increases the revenue of farmers' household, as well as the quality of the soil in the study area, what is the improvement induced by FMNR on household income? Does the adoption of FMNR lead to an increase in household access to a variety of foods?

This study will:

- Determine the changes induced or resulting from FMNR on household income in the Nord Plateau Mossi.
- Determine the impacts of FMNR on household dietary diversity and in the obtaining of firewood.
- Identify the changes generated by FMNR in soil fertility (soil organic matter, total nitrogen, total carbon, cation-exchange capacity [CEC], potential of hydrogen [pH], total exchangeable base cations [TEBC], base saturation [BS], and soil temperature).

I hypothesize that the practice of FMNR leads to increases in income, dietary diversity, food security, and ability to obtain firewood, and soil fertility.

CHAPTER 2: LITERATURE REVIEW

This chapter examines scholarly literature about the relationship between sustainability and geography, environmental issues, and farmer managed natural generation. This chapter aims to survey previous research on the connection between sustainability and geographic studies, as well as on the ability of geographers to address environmental issues. Additionally, I used reference work to address farmer managed natural regeneration definition and impacts. This chapter also focuses on Burkina Faso ecological and agroeconomic background, as well as land use and land cover change.

2.1 Sustainability in Geography

The term sustainability was propagated in 1987 by the United Nations (UN) *Brundtland Report*; however, our modern understanding of sustainability has some roots in an earlier concept called carrying capacity that was part of the Malthusian debate. "Carrying capacity refers to the maximum abundance of a species that can be sustained within a given habitat" (Freedman 2014, 805). The term sustainability was used in 1972, in a UN conference at Stockholm, but geographers were using the term in the 19th century (Mulligan 2015, 11; Bonney et al. 2014, 1). The roots of the field of sustainability lies in the field of geography, therefore it is legitimate then to say that sustainability is part of the field of geography (Bonney et al. 2014, 14; Liu 2011, 249).

Sustainable development, which refers to processes to achieve sustainability, aims to meet the needs of the current generation without exposing future generations to a lack of resources for their own needs. This is a human-environment system and both components need to be fully mastered. Geography is one of the most effective ways to approach this concept, because of the ability of geographers to understand places and understand how human actions shape the landscape. The Triple Bottom Line organizes the concept of sustainability into three parts, economic, environmental, and social dimensions (Koth 2013, 558; Wichaisri, and Sopadang 2018, 1).

2.2 Geographic Environmental Issues

It seems obvious that environmental studies are part of the field of geography. After the release of the defined sustainable development by the UN's World Commission on Environment and Development, geographers slowly worked on the physical environment component of the issue. Nonetheless, geographers have discussed environmental education, natural resources, or more broadly sustainability (e.g. Kates and Parris 2003; Kates et al. 2001; Harden 2009; Wilbanks 1994). As highlighted by the former UN Secretary General Kofi Annan at the annual meeting of the Association of American Geographers (AAG) in New York on March 1, 2001, geographers have an affinity with environmental issues such as climate change and global environment. In other words, they can understand the environment in the sense that people need to adjust their needs and activities to nature (Eflin, and Sheaffer 2006, 33; Kates 1987, 526; bers 1923, 4). Geography and sustainable development are closely linked because they share many research interests such as "globalization, environmental problems, and applications of Geographic Information Systems" (Wilbanks 1994, 546).

2.2.1 Inappropriate Land Management

Humans do not always think of adapting themselves to the environment, which may result in the destruction of the ecosystem. Even if scientific discoveries through human history have made people less dependent on nature, tremendous changes and modification of the environment by human activities are still likely to occur. In the case of Africa, rapid population growth and poor technological progress have kept the communities dependent on the land. For example, demographic pressure caused the destruction of forest areas in Uganda (Jiang, Bamutaze, and Pilesjo 2014, 40). Charcoal extraction and lumber exports influenced forest degradation in Tanzania (Ahrends et al. 2014, 14558). In Kenya, immigration into arid and semi-arid lands caused land degradation and desertification (Darkoh 1998, 10). The relationship between population and resources created the conditions of an important desertification, and deforestation in some African countries. In other words, human activities combine with climatic conditions are the driving forces of the degradation of the land. Overgrazing, urban expansion, and agriculture are key factors degrading the environment (Tougiani, Guero, Rinaudo 2009, 378; US Committee on Foreign Relations 2000, 2; Jiang, Bamutaze, and Pilesjo 2014, 39). Uganda, Niger, and Tanzania are some examples where human activities affected the environment negatively (Jiang, Bamutaze, and Pilesjo 2014, 40; Ahrends et al. 2014, 14558; Tougiani, Guero, and Rinaudo 2009, 379).

2.2.2 Poverty and Hunger

Poor land management may lead to further issues such as poverty and hunger because of the limited resources on earth. In general, the proportion of people severely affected by hunger or extreme poverty is declining however this decline is very slow in much of Africa (International Food Policy Research Institute 2015, 74). Rural development, government policy, public health, and agricultural production are the main factors that influence food insecurity around the world, especially in Africa (Melito 2008, 2).

If agriculture is a cause of poverty, and hunger in Africa and in the Sahel, it can be a solution to those phenomena striking and retarding rural development (Scaling Up the Fight Against Poverty and Hunger in Africa 2012, 1). Sahelian countries often have droughts, desertification, inappropriate agricultural practices, low agricultural productivity, poor health care for farmers, and increases in food prices. Additionally, agriculture is the driver of the Sahelian economy (Kusserow 2017, 1142). The resolution of these agricultural issues may contribute to the fight against poverty and hunger in the Sahel, and in the continent in general.

2.3 Farmer Managed Natural Regeneration

2.3.1 Definition

Farmer managed natural regeneration consists of the protection and management of naturally regenerated trees to increase the value and quantity of woody vegetation on farmlands. After the severe droughts and famine that occurred during the 1970s, some farmers in Niger, in the 1980s, realized that many of the severe impacts of the droughts they suffered were the result of cutting trees for short-term gains (Reij, Tappan, and Smale 2009b, 55). This awareness led to a shift of mindset, and some farmers began to protect trees and allowed them to regrow. The idea of tree protection diffused across much of West Africa from the innovative farmers. By protecting trees, farmers established a low-cost system to restore degraded land, improve agricultural production, and improve forest and pasture land. There are three main ways to regenerate woody species (Reij and Winterbottom 2015, 15). First, regreening is possible through animal manure. Animal manure often contains seeds from trees and bushes browsed by cattle. They then drop seeds in their manure when grazing and spread new trees (Reij and

Winterbottom 2015, 15). In addition, by using manure as fertilizer in their croplands, farmers contribute to regreening through manure. Secondly, natural regeneration is possible through the underground forest (Rinaudo 2007, 32). The underground forest is the existing roots and stumps in the ground from trees that were cut before. In this process, farmers allow sprouts from stumps to grow, and then protect those natural grown trees (A quiet revolution 2013, 4). Finally, natural regeneration is possible through the soil's seed memory. This represents the seeds stored in the topsoil, sometimes for years, that may sprout under the right rainfall (Reij and Winterbottom 2015, 15). Farmers who adopt FMNR, intentionally increase the number of trees on their farmland. By using this technique, farmers expect to obtain benefits such as improved soil fertility, increased fuelwood, improved household food security, and so on (Reij and Winterbottom 2015, 3).

2.3.2 Impacts

The literature about the positive impacts of FMNR remains embryonic, but little has been written about its negative effects. FMNR helps maintain and improve soil fertility. Trees can improve soil fertility in two ways. First, employing a process that involves biomass production. Trees can improve soil fertility by increasing soil organic matter (Reij and Winterbottom 2015, 23) when soil organisms convert organic matter from dead roots, leaves, and plants into nutrients for their consumption, and release excess nutrients into the soil in forms that plants can use (Montgomery 2017, 46). Secondly, some trees can improve soil fertility by fixing nitrogen, which serves as a fertilizer for the soil. In dry areas such as Mali, Niger, or Burkina Faso, legumes such as *Piliostigma reticulatum*, as well as other plants such as *Guiera senegalensis* and

Faidherbia albida help increase the quality of the soil by fixing nitrogen from the air (Barnes and Fagg 2003, 23).

In addition, FMNR improves household food security by enhancing crop yields. For farmers, an increase in agricultural yields means that more food becomes available for consumption as well as for sale. Trees also provide various products for household consumption or to be sold for cash such as fruits, leaves (vegetables), fodder for livestock, firewood, poles for construction, medicinal products, and so forth (Reij and Winterbottom 2015, 25). The baobab or *Adansonia digitata* is another example of a tree that provides extra resources for farmers. In fact, "baobabs are pruned for their leaves, which are widely used to make sauces. Usually the leaves are dried, powdered, and used for cooking during the dry season. The mealy fruit pulp (monkey bread) is used in cool and hot drinks" (Schumann 2010, 2036). Additionally, FMNR helps farmers adapt to climate change by reducing wind speed, reducing soil surface temperatures, mitigating climate change by sequestering carbon, providing a source of household energy, and contributing to biodiversity conservation and restoration of ecosystem services (Reij and Winterbottom 2015, 23-29; Haglund et al. 2011, 1700; Reij, Tappan, and Smale 2009a, 17-28).

The impacts of FMNR are so important that government organizations, such as the African Forest Landscape Restoration Initiative (AFR100) promote the positive impacts of trees in people's lives to increase self-sufficiency and family income (WRI, NEPAD, BMZ 2016, 3). These impacts are the reasons why "over the past 20 years, hundreds of thousands of farmers in Burkina Faso, Mali, Niger, and Senegal have invested in protecting natural regeneration and in increasing the number of on-farm trees" (Reij and Winterbottom 2015, 23).

2.4 Farmer Managed Natural Regeneration in Burkina Faso

2.4.1 Burkina Faso Ecological and Agroeconomic Background

Burkina Faso, formerly known as Upper Volta, "is a landlocked country that spans across the semiarid Sahel and the more humid Sudan bioclimatic zone" (CILSS 2016, 82). It has 274,200 square kilometers and is approximatively the size of Colorado (Figure 4). From north to south, the country can be divided into three main general bio-climatic regions (Figure 5): Sahel, Sudan Savanna, and Northern Guinean (Gelb et al. 2015, 18). Bio-climatic regions are divisions of the landscape that are classified based on climate drivers that enable and constrain vegetation patterns such as temperature, rainfall, moisture balance, and altitude (Balasubramanian 2011, 2). Bio-climatic regions might have different ecoregions. The Sahel, Sudan Savanna, and Northern Guinean bio-climatic regions are associated with the long-term precipitation variability of Burkina Faso. They are characterized by differences in annual rainfall, and natural vegetation (Gelb et al. 2015, 18). Low rain (up to 400 mm) and poor soil fertility make agriculture a challenge throughout the Sahel. The Sudan Savanna receives an average annual rainfall between 500 and 1,000 mm and has a low tree density and a high concentration of farmlands (Gelb et al 2015, 18). The Northern Guinean Savanna ecoregion has an average annual rainfall between 1,000 and 1,400 mm (Gelb et al. 2015, 18).

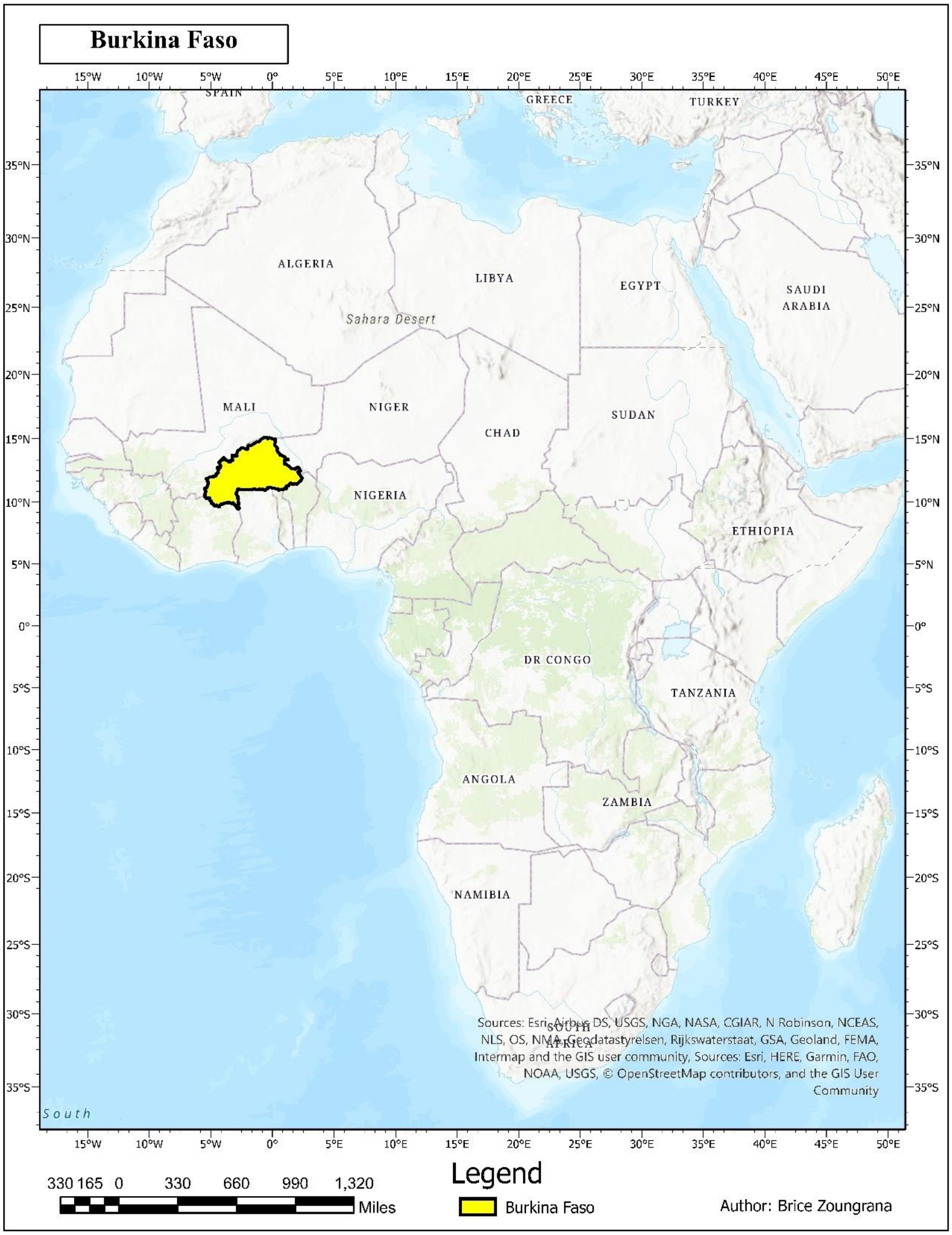

Figure 4. Burkina Faso location map

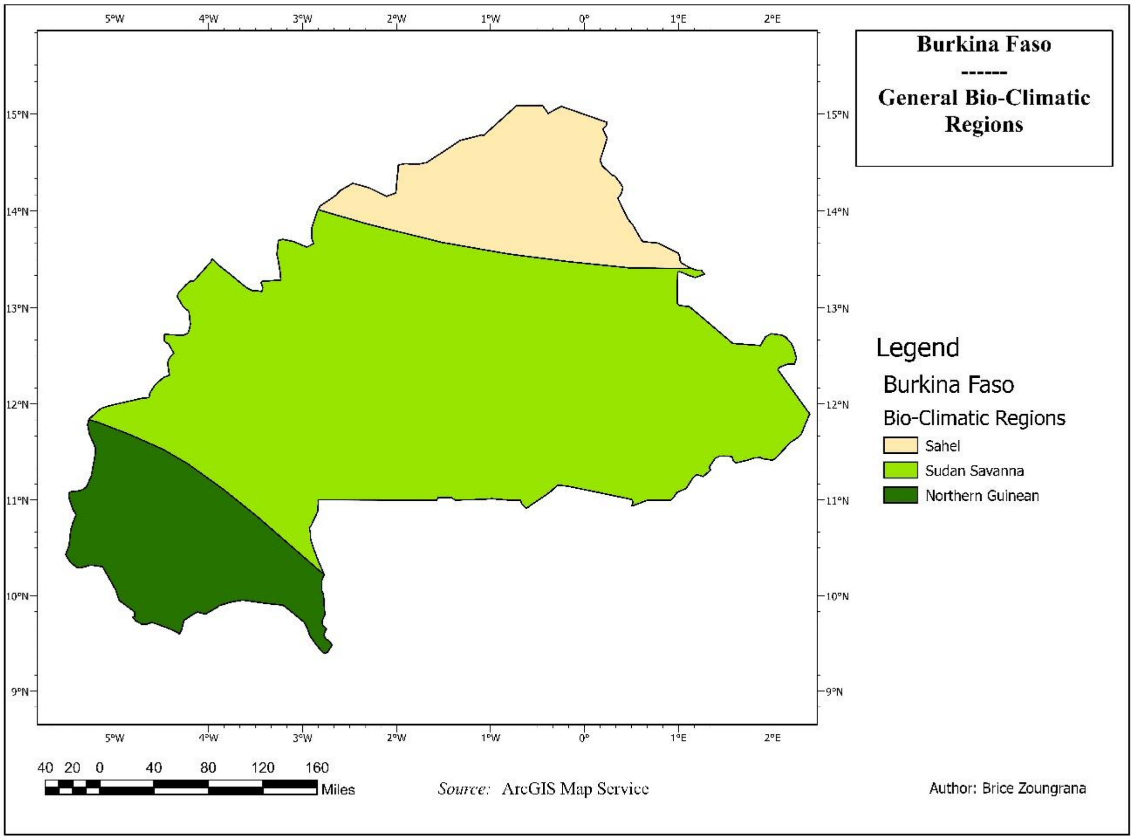

Figure 5. Burkina Faso general bio-climatic regions

Burkina Faso's economy relies primarily on agriculture. The agricultural sector employs about 80% of the active population (all employed and unemployed people) and contributes about a third of the country's Gross Domestic Product (USAID 2019). Sorghum is the dominant crop in terms of cultivated area (Figure 6) and agricultural production (Figure 7). Farming systems can change from one region to another based on the climatic and socio-economic conditions as well as the type of soil. Small family farms that mainly operate during the rainy season (July to October) predominate. In addition, Burkina Faso faces major agricultural constraints such as unpredictable rainfall, poor soils, and lack of equipment (Korodjouma 2020).

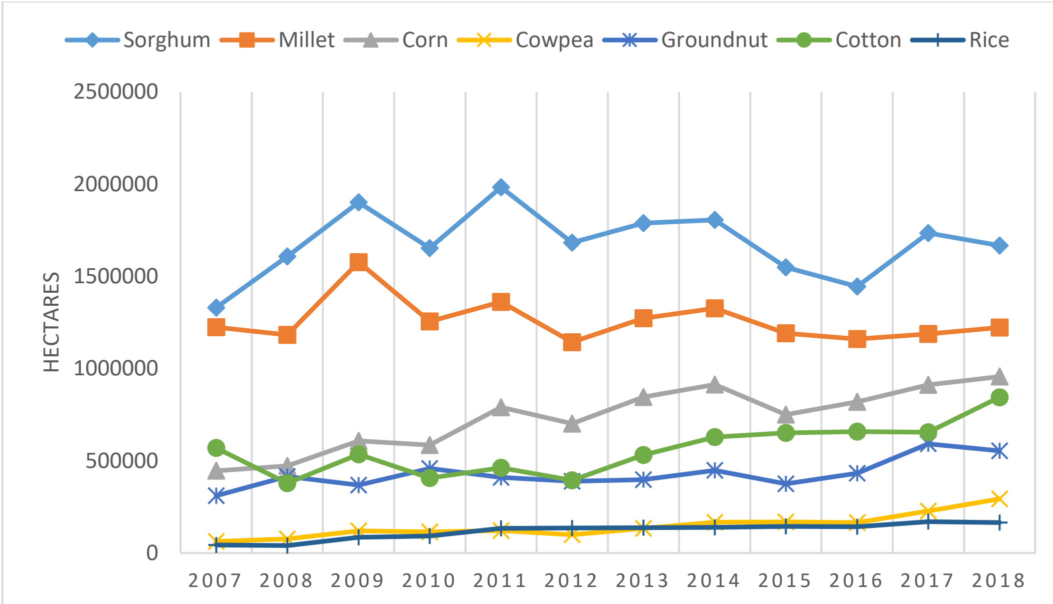

Figure 6. Cultivated area in hectares by crop type in Burkina Faso

Source: Adapted from Burkina Faso National Institute of Statistics and Demographics, 2018.

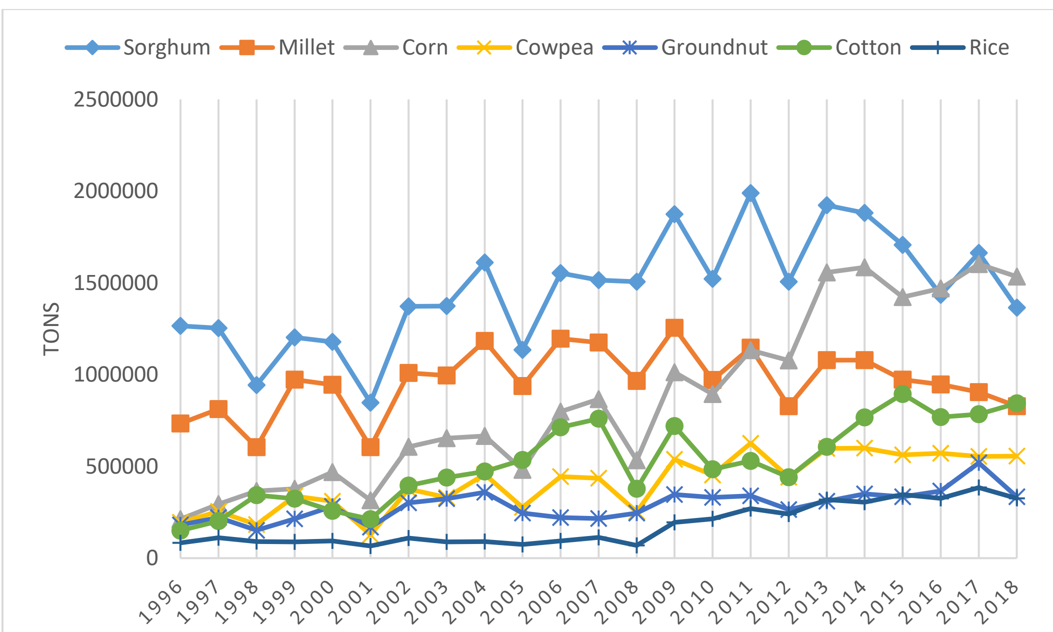

Figure 7. Agricultural production in metric tons by crop type in Burkina Faso

Source: Adapted from Burkina Faso National Institute of Statistics and Demographics, 2018.

2.4.2 Land Use, Land Cover Change

In 1975, Burkina Faso's landscape was dominated by savannas, however, human activities, including agriculture have changed the land cover. In 1975, 82% of the country's "land was still covered by natural land cover classes (forest, gallery forest, savanna, steppe, or rocky land)" (CILSS 2016, 84). By 2013, only 57% of Burkina Faso's land was occupied by the same land cover classes (CILSS 2016, 84). The expansion of agricultural land and croplands (increased respectively from 29.7% and 7.8% in 1961 to 44.2% and 22.3% in 2017) played an important role in decreasing woody vegetation (Figure 8). Agricultural land is a "land area that is either arable, under permanent crops, or under permanent pastures" (OECD 2020) and cropland is a land use category that "includes areas used for the production of adapted crops for harvest" (USDA 2020). In addition, Burkina Faso (especially the central part) suffered from issues such as low and highly variable rainfall (Figure 9), growing food deficits, low and declining cereal yields, disappearing and impoverished vegetation, falling ground-water levels because of droughts, and the arrival of internally displaced people (Reij, Tappan, and Smale 2009a, 3; Reij, Tappan, and Belemvire, 645-647).

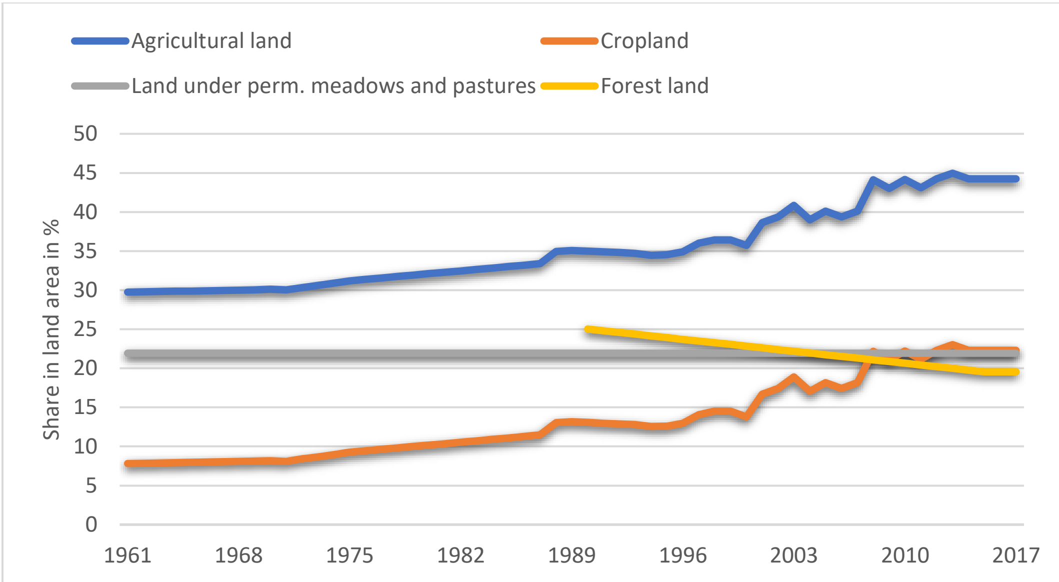

Figure 8. Agri-environmental land use indicators in Burkina Faso

Source: Adapted from Food and Agriculture Organization of the United Nations (FAO), 2018.

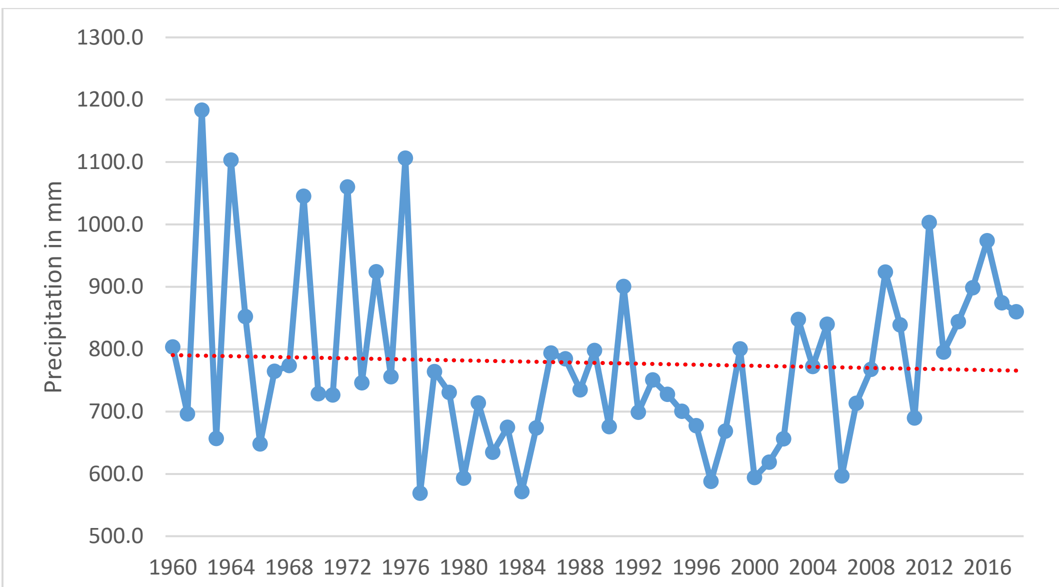

Figure 9. Annual precipitation data from central Burkina Faso from 1960-2018 (Ouagadougou airport station)

Source: General Directorate of Meteorology, Burkina Faso.

From 1910 to 2014, Burkina Faso suffered from thirteen droughts (Table 1). The droughts from the 1970s and 1980s (Figure 10) led to a substantial displacement of farmers from the northern part (about 25% of villagers) to the southwestern part of the country, where there was more rainfall and fertile soils (Reij 2014). This increased land pressure in southern Burkina Faso. In response to the droughts mainly after 1980, several farmers in northern Burkina Faso started to adopt soil conservation techniques, which rapidly spread to other parts of the country (Reij, Tappan, and Smale 2009b, 54). Improved planting pits also known as Zaï is one of these methods (Gelb et al 2015, 28; Reij, Tappan, and Smale 2009b, 54). The technique of Zaï consists of a series of man-made pits of approximately 10–20 cm deep and 20–30 cm wide that concentrate nutrients and moisture (Ndah et al. 2014, 624; Schuler et al. 2016, 989). Another technique used is contour stone bunds, a barrier formed of stones that runs along land of equal elevation (Reij, Tappan, and Smale 2009a, 6; Reij, Tappan, and Smale 2009b, 55). Farmers used this technique based on a traditional farming practice in the late 1970s and early 1980s to keep water and nutrients from running away from the farmlands with support from Oxfam (Reij, Tappan, and Smale 2009a, 4; Reij, Tappan, and Belemvire, 653).

Table 1. Drought inventory

Start Year	Start Month	End Year	Location	Associated Disaster	Total Population Affected	Total Population	% of Total Population Affected
1910	-	1914			No data	No data	
1940	-	1944		Famine	No data	No data	
1966	7	1966	Nationwide		No data	5,256,363.00	
1969	4	1975	East, North of Ougadougou. Northern section	Famine	975,000.00	5,528,174.00	18%
1977	-	1978	Nationwide		442,000.00	6,398,935.00	7%
1980	11	1985			1,250,000.00	6,822,843.00	18%
1988	-	1988	North	Crop failure	200,000.00	8,356,305.00	2%
1990	12	1990	North and Central provinces		2,600,000.00	8,811,034.00	30%
1995	12	1996	Bam, Kadigo, Outbritenga, Oudalan, Sanmatenga, Seno, Soum, Yatenga provinces	Food shortage, Famine	75,590.00	10,089,878.00	1%
1998	3	1998		Food shortage	20,700.00	10,968,724.00	0.2%
2001	4	2001	Plateau Central province		No data	11,944,587.00	
2011	12	2012	Sahel, Centre-nord, Est, Centre-ouest and Centre-est provinces	Food shortage	2,850,000.00	16,081,913.00	18%
2014	5	2014	Sahel province	Food shortage	4,000,000.00	17,586,030.00	23%

Source: adapted from EM-DAT, 2020 and Food and Agriculture Organization of the United Nations (FAO), 2018.

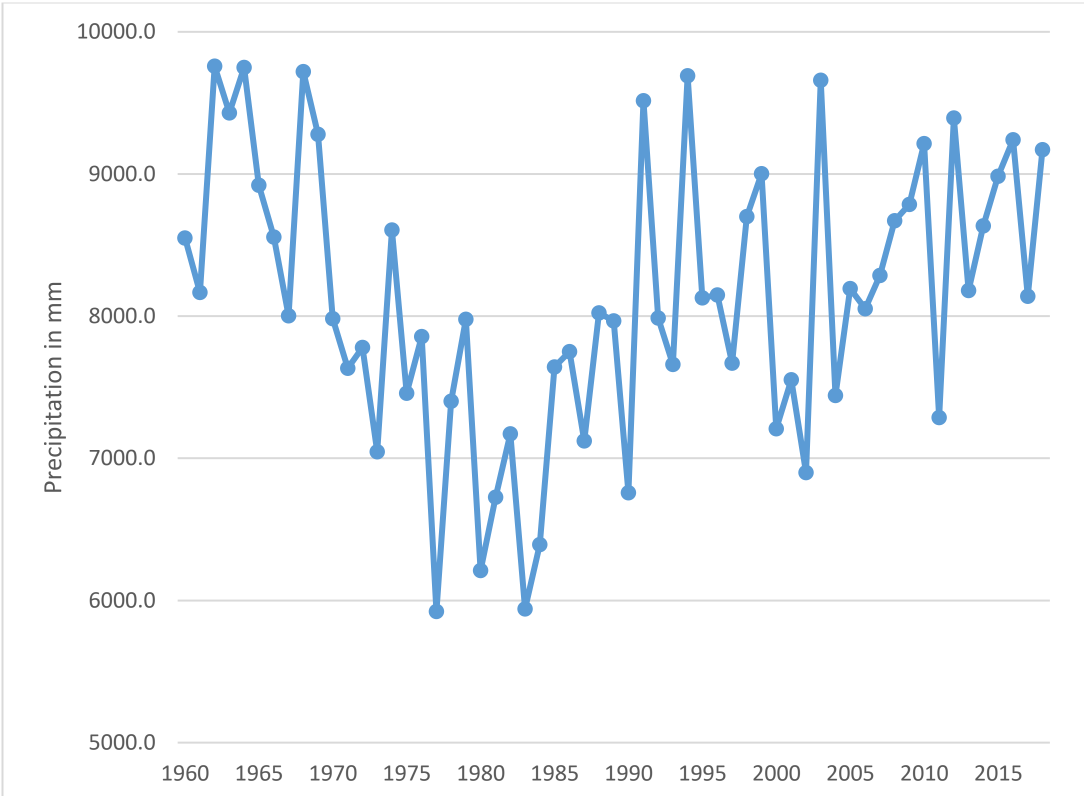

Figure 10. National average precipitation in Burkina Faso from 1960 to 2018

Source: General Directorate of Meteorology, Burkina Faso.

2.5 Data Collection Case Study

I used the study "Changing Land Management Practices and Vegetation on the Central Plateau of Burkina Faso (1968–2002)" (Reij, Tappan, and Belemvire. 2005) as reference for the methodology. The authors discussed Soil Water Conservation and its impacts on agriculture and environment in Burkina Faso. They conducted a survey in twelve villages characterized by the level of investments in soil water conservation. Nine of the villages presented significant investments as well as a long history of soil water conservation, and the other three had no investments. This study focused on surveying different households in the selected villages and collecting data on agriculture for the analysis (Reij, Tappan, and Belemvire, 644-645).

To summarize, the review of literature in this chapter revealed that geography is one of the most effective ways to approach the concept of sustainability, because geographers understand places and understand how human actions shape the landscape. Unfortunately, humans do not always think of adapting themselves to the environment leading in some cases to inappropriate land management, poverty, and hunger. The literature also revealed that although human activities can cause environmental issues, they can also be a solution to environmental problems. Farmer managed natural regeneration is an example of a sustainable agricultural practice that increases soil fertility, improves household food security, and helps farmers adapt to climate change.

CHAPTER 3: METHODS

This chapter describes the steps taken to address the research questions. To reach my objectives I collected data in five villages within the Nord Plateau Mossi. I used focus groups to interview farmers to learn their motivations for choosing whether to adopt FMNR. To determine the nutritional adequacy of farm households, I used household dietary diversity surveys. Additionally, I collected soil samples under and away from trees to assess their impact on soil fertility.

3.1 Data Collection Sites

Initially, this study was designed to collect data in ten villages using a stratified sampling method to divide the population studied into groups or strata (Sullivan 2009, 2). The use of this method allows comparison between sampled areas. The villages within the study area were divided into two groups of five villages each, depending on the presence or absence of FMNR. I used Geographical Information Systems and photo interpretation to select the villages with FMNR, as well as the villages without FMNR in the study area. Photo interpretation is "the act of examining photographic images for the purpose of identifying objects and judging their significance" (Paine 1981, 252). Said differently, it is the study of ground objects and patterns using aerial photographs (Verstappen 1988). This method emphasizes visual interpretation and allows the interpreter to recognize features on remotely sensed images by associating their color, size, shape, texture, pattern, height shadow, and site association to real features on the ground (Figure 11). At scales of 1:40,000 or larger, visual interpretation is used to extract information from fine resolution imagery (Millett 2019). Concretely, this research used high resolution images of the study area from Google Earth at a scale of 1:8,000 to visually identify and select villages with and without FMNR. Using the Grid Index Features tool on ArcGIS Pro, the study area was divided into 1,000 meter grids, and imported into Google Earth Pro (Figure 12) to facilitate the interpretation process.

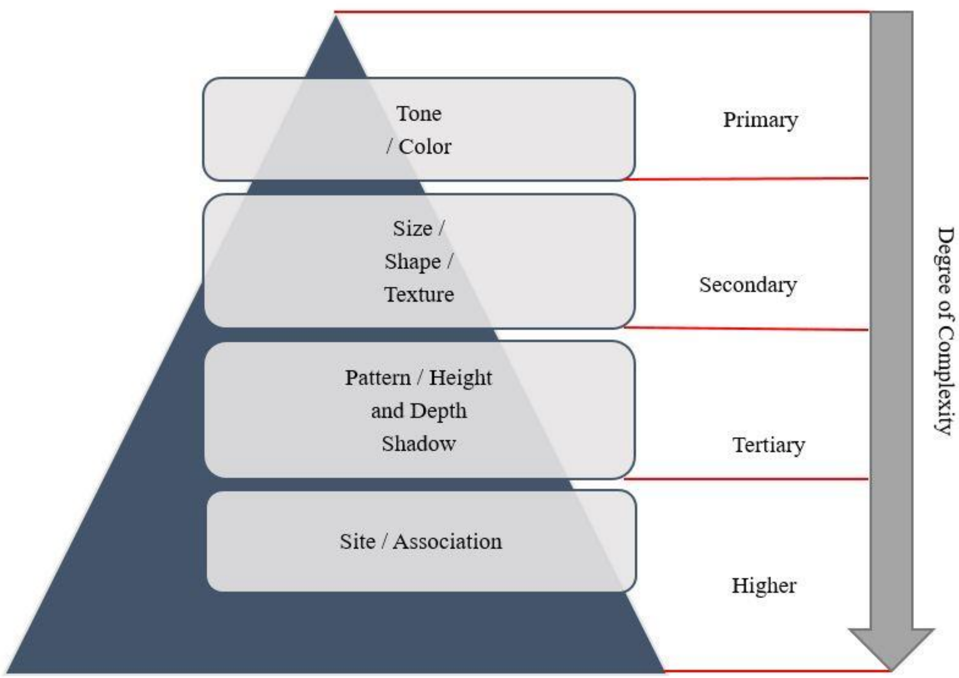

Figure 11. Primary ordering of image elements fundamental to the analysis process

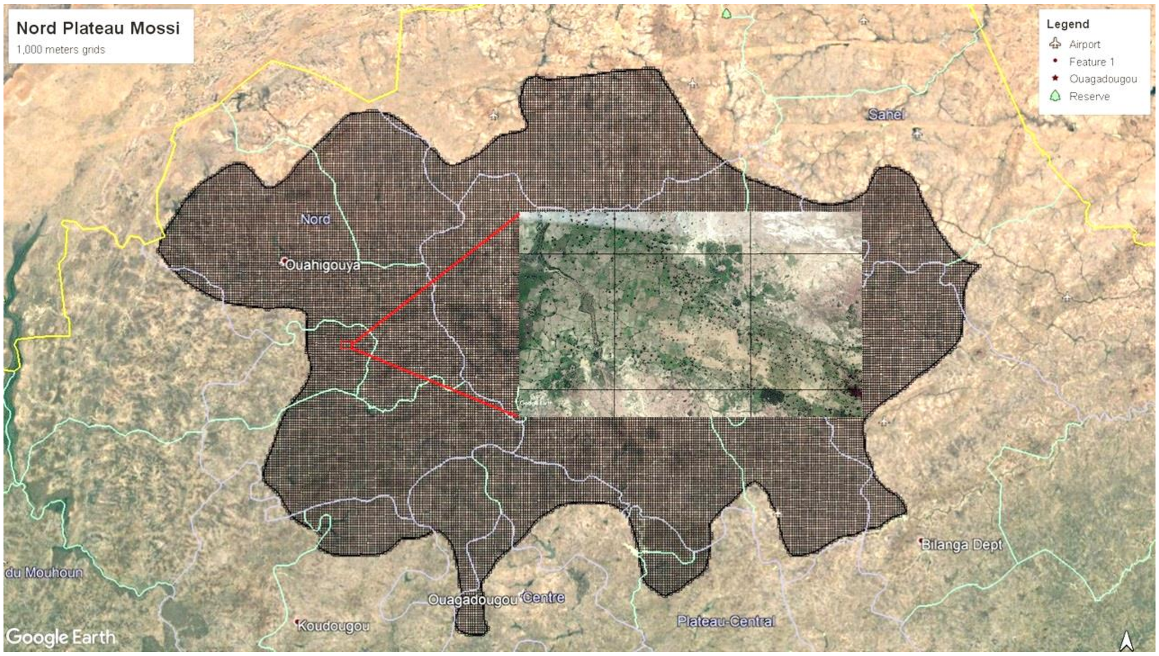

Figure 12. Grid index features of the study area

After arriving in Burkina Faso to conduct field work, I had to change the sampling method because of terrorist movements in the country especially in the northern part (any area within 80 km of the Burkina Faso-Mali border should be avoided [Government of Canada 2018]). In collaboration with NGOs that promote FMNR in Burkina Faso (SOS Sahel and Buud Nooma Association), I selected within the study area five villages with FMNR, Boala, Kaoukouagin, Mogodin, Safi, and Tema (Figure 13). Farmers in these villages are organized within these two NGOs. Three factors, accessibility, safety, and the availability of a representative from the NGOs played a key role in selecting the villages. Representatives from the NGOs helped me approach the farmers in the villages, briefly tell them about the study, and set up a meeting time. Farmers in the villages of Boala, Kaoukouagin, Mogodin, and Safi (Figure 13), are organized within the NGO “SOS Sahel”. This NGO mission is “to improve the food security and nutrition of rural communities in sub-Saharan Africa” (SOS Sahel 2016). In the village of Tema, farmers are organized within the NGO “Buud Nooma Association”, which means “family is good” in Moré, the local language (Buud Nooma Association 2020).

In terms of spatial distribution, the sampled villages differ from those that I developed the methodology for. Initially, this research was designed to collect data in villages distributed across the central and southern part of the study area. With the sampling method used to select the villages from the field, four of the five sampled villages are clustered at the edge of Nord Plateau Mossi. This reduces the diversity of opinions in the motivations of farmers for choosing whether to adopt FMNR, as well as in the determination of the nutritional adequacy of farm households.

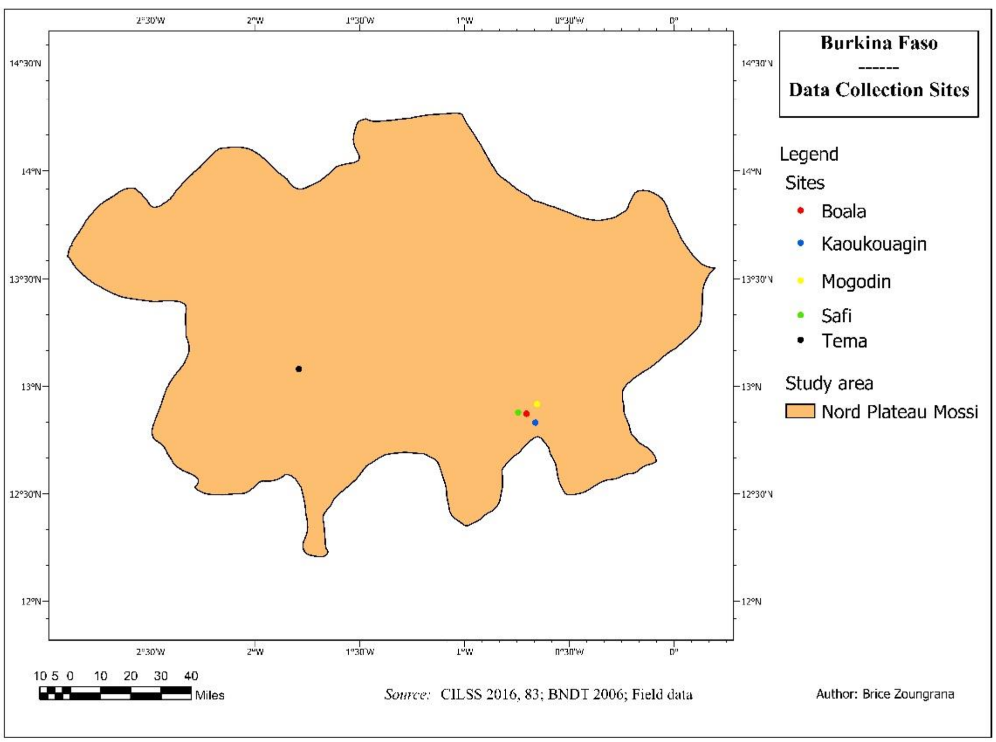

Figure 13. Data collection sites

The villages of Boala, Kaoukouagin, Mogodin, and Safi are located in the commune of Boala, in the Namentenga province. These villages are part of a region relatively isolated and little subject to external influences. The villages kept alive their traditional way of life, costumes, customs, and animist religion. The main source of household income comes from agriculture and animal husbandry. The dominant ethnic group in the villages of Boala, Kaoukouagin, Mogodin, and Safi is the Mossi. Additionally, the village of Boala is home to a small Fulani community. The national road Nº15 crosses the villages of Boala (Figure 14) and Safi (Figure 15), making them more accessible than the other villages. The village of Mogodin is about 6.5 km away from the national road Nº15 (Figure 16), and the village of Kouakaougin is about 2.1 km away from the national road (Figure 17). Accessibility to these last two villages is challenging especially during the rainy season because of the presence of floodplains between the national road and the villages. It is almost impossible to enter or exit Mogodin or Kaoukouagin when it rains. About 73% of the soils in the commune of Boala are poorly developed soils on gravelly materials, and about 22% are tropical ferruginous soils (Institut Géographique du Burkina 2002; 2014). Overall, the commune of Boala is characterized by fragile soils, subject to strong erosion, accentuated by high rural population density and pressure, and traditional agropastoral practices of the Mossi (D'Keng Taoré 2009).

The village of Tema is located in the commune of Bokin, in the Passore province. The village is about 5.4 km from the capital of commune, the town of Bokin, and about 108 km from Ouagadougou, the capital of Burkina Faso. Like the villages of Mogodin and Kouakaougin, the village of Tema is quite inaccessible when it rains because of the presence of floodplains along the dirt road from the town of Bokin to the village. The relief in the village of Tema, as well as in the commune of Bokin is flat, dominated by low-lying Birrimian hills (Sankara 1993, 19). The soils are mainly sandy clay soils. Rain-fed agriculture is the primary source of income (Figure 18, Figure 19).

The following table gives some basic characteristics of the five villages.

Table 2. Basic characteristics of the sampled villages

Villages	Location	Commune	Population (2006 Census)	Total Terroir Area (km^2)	Cropland area (%)	Percent FMNR within Cropland		
						Dense	Medium	Low to No
Boala	12°52'24.24" N; 0°42'5.67"W	Boala	3,415	24	70.79%	26.13 %	60.12%	13.75%
Kaoukouagin	12°49'52.70" N; 0°39'46.01"W	Boala	450	17.6	71.43%	20.46 %	71.71%	7.83%
Mogodin	12°54'59.08" N; 0°38'56.84"W	Boala	1,382	25.7	50.23%	15.26 %	76.44%	8.30%
Safi	12°53'0.58"N; 0°44'31.47"W	Boala	1,308	15.4	59.07%	10.77 %	83.38%	5.85%
Tema	12°58'47.23" N; 1°49'13.59"W	Bokin	-	13.7	61.33%	20.65 %	71.33%	8.02%

Figure 14. Labeled satellite view of Boala

Figure 15. Labeled satellite view of Safi

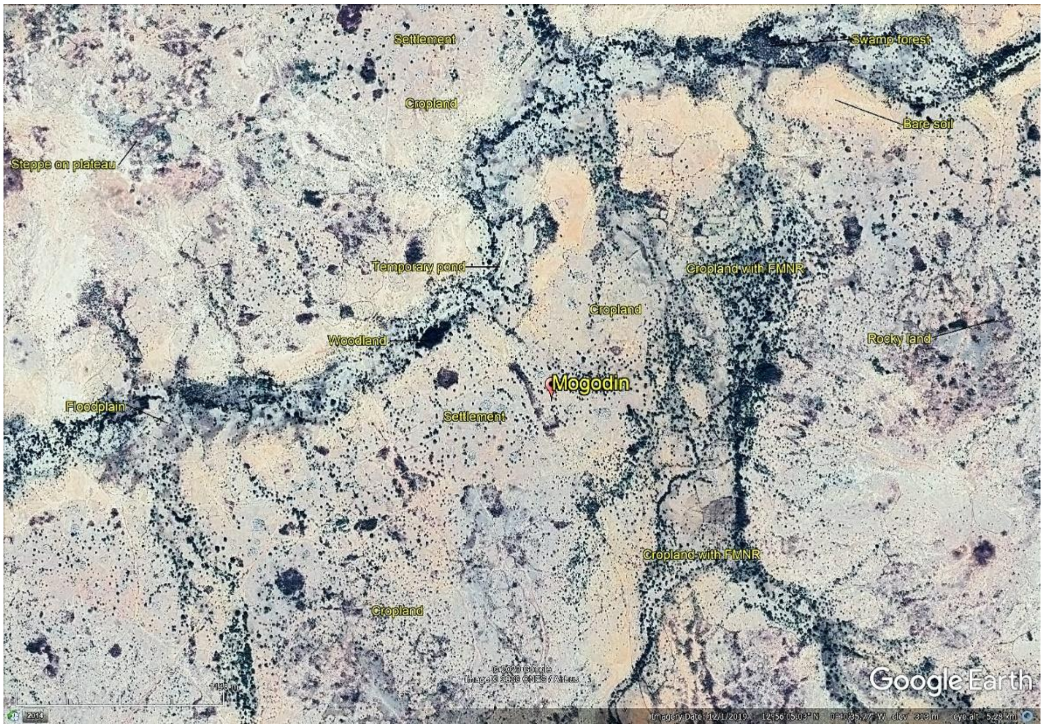

Figure 16. Labeled satellite view of Mogodin

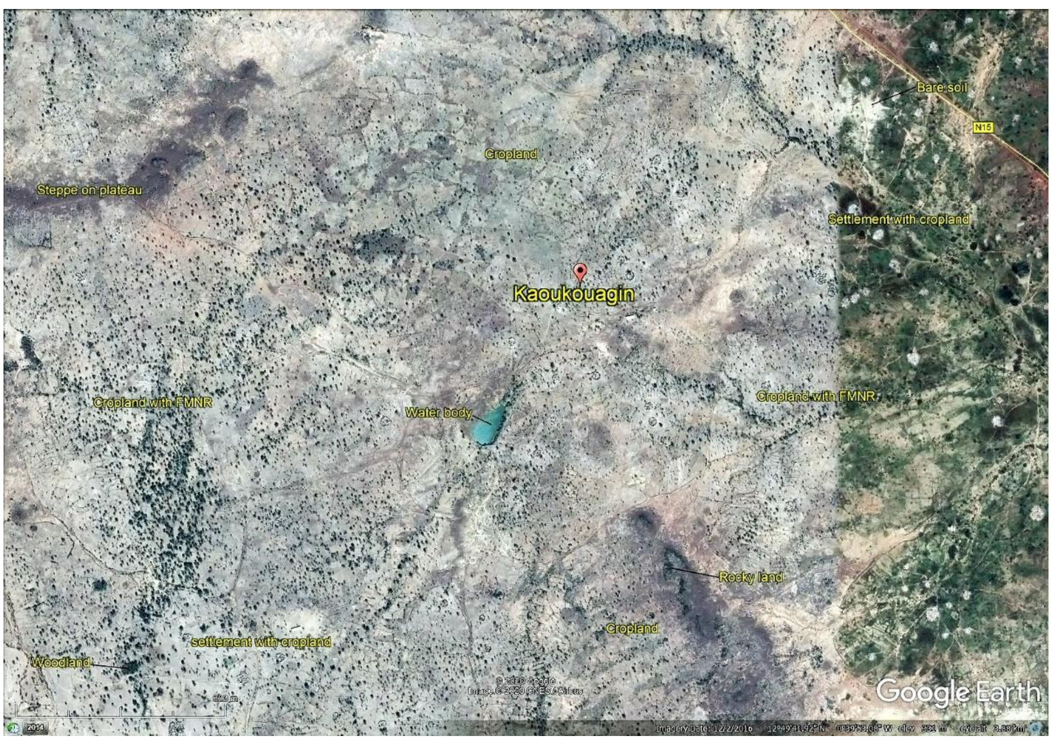

Figure 17. Labeled satellite view of Kaoukouagin

Figure 18. Labeled satellite view of Tema

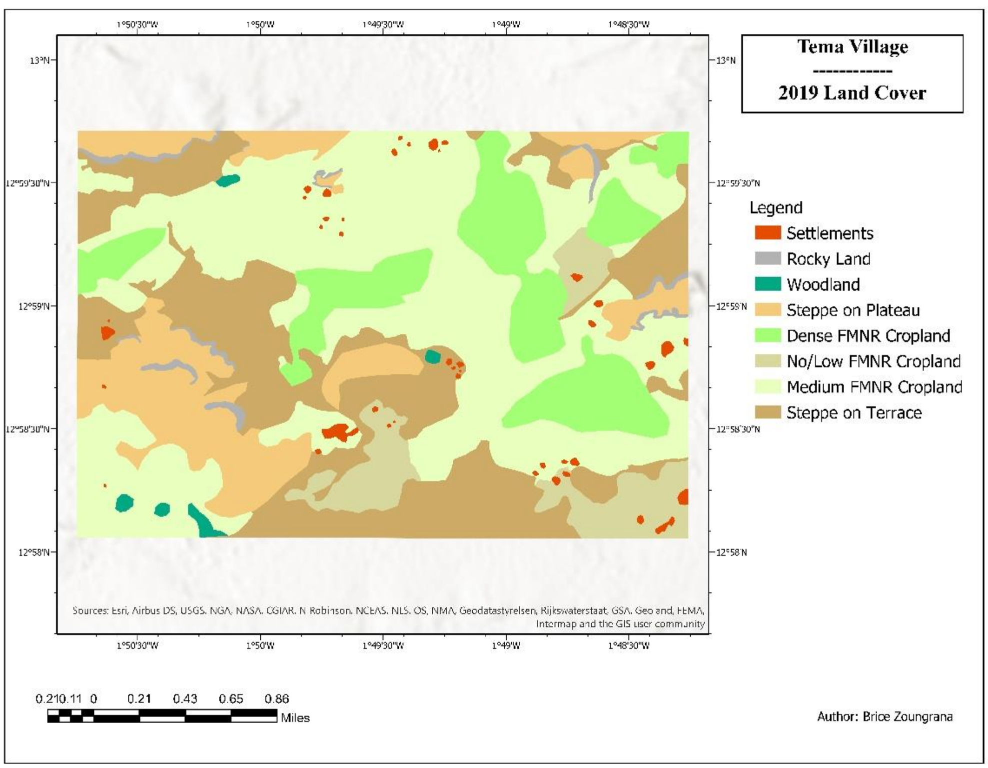

Figure 19. Village of Tema 2019 land cover

3.2 Interviews

I used focus groups to interview farmers in five villages to learn their motivations for choosing whether to adopt FMNR. Focus groups provide information about what people think and why they behave in particular ways (Hay 2016, 206). I used semi-structured interviews within those focus groups, giving the advantage of ordered but flexible questioning (Hay 2016, 158). In other words, I used an interview schedule (list of carefully worded questions) but I was not limited to deploying these questions during the interview (Hay 2016, 152,158). The discussion encouraged and valued different opinions and ideas. To develop the questions, I used the study "Dynamics of Biodiversity and Human Carrying Capacity in the Senegal Sahel" (Gonzalez 1997, 86-89) as a reference.

The purpose of focus groups is to gather opinions and beliefs, attitudes, and knowledge from a well-informed set of participants (Gavora 2015, 11). In this study, the number of participants varied between six and eight. This size of group encourages discussion without limiting the time available for individual participant participation (Hay 2016, 210). I conducted two separate focus groups, one of men (Image 1), and one of women (Image 2) per village. The group setting allows the participants to consider different perspectives and ideas. In addition, gender is an important factor in this research to evaluate the impacts of FMNR on household nutritional adequacy and obtaining of firewood because women are responsible for the household meals and firewood (Gyasi 2004, 185). The participants in the focus groups were adult farmers (25 years old or more) exclusively, because it was important for them to be knowledgeable about the impacts of FMNR. In addition, because it was important for participants to be comfortable and reliable, the local representatives of SOS Sahel and Buud Nooma Association helped me approach the farmers in their respective villages.

Although the sampling method used in this study was village-based, the data collection was farmer-centered, because FMNR is a farmer-led initiative. In other words, data collection focused on farmers and their experience with FMNR. Additionally, local village chiefs played an important role in gathering farmers for focus group interviews, because people cannot be gathered without their permission (Image 3). I used note taking and audio recording to record the focus groups. Focus group conversations were about the changes induced by FMNR on household income, dietary diversity, and the availability of firewood in the study area.

Image 1. Focus group with men from Mogodin

Image 2. Focus group with women from Boala

Image 3. Photo with the chief of Tema: person sitting on the chair dressed in blue

To determine the nutritional adequacy of farm households, I used the Food and Agriculture Organization of the United Nations (FAO) household dietary diversity survey. Dietary diversity is a qualitative measure of household food consumption, reflects family access to a variety of foods, and is a proxy for the nutrient adequacy of the diet of individuals (FAO 2011, 5). The questionnaire focused on women because they are the ones in charge of the household's meals (Image 4). I surveyed the same women from the focus groups and none of them refused to answer. This increased the time commitment by women, as women's focus groups were not shorten to accommodate them. Based on the data collected from the survey, this study evaluated nutritional adequacy by using a household dietary diversity score, "which is the sum of the different food groups consumed" (FAO 2011, 23) in the household over the last 24 hours. The food groups used to calculate the household dietary diversity score were cereals; white roots and tubers; vegetables; fruits; meat; eggs; fish and sea food; legumes, nuts, and seeds; milk and milk products; oils and fats; sweets; and spices, condiments, and beverages.

Image 4. Household dietary diversity survey with a woman from Kaoukouagin

3.3 Soil Sampling

In addition to focus group interviews, I collected soil samples under and away from trees to assess their impact on soil fertility (Image 5). Soil sampling focused on two groups of mature trees (a trunk diameter of 75 centimeters or more at breast height) in each village (with the exception of the village of Mogodin):

- Group 1: *Faidherbia albida* tree (Image 6)
- Group 2: Other tree species.

The first samples focused on soils near *Faidherbia albida* trees, which are known to improve soil fertility (Reij, Tappan, and Smale 2009a, 8). *Faidherbia albida* is a nitrogen-fixing tree and is recognized by farmers to be beneficial to crop yields (Tougiani, Guero, and Rinaudo 2009, 381), because “nitrogen is an important limiting nutrient for plant production in arid and semiarid ecosystems” (Aranibar 2003, 346).

I took three soil samples, one under the canopy (near the trunk) of a mature *Faidherbia albida* tree, another fifteen meters away from it, and a third thirty meters away from it. Then three other soil samples under the canopy of a mature tree other than *Faidherbia albida*, and fifteen and thirty meters away from it. Each sample was a mix of four different cores or subsamples of the same area (within a sixty centimeter radius circle) taken at a depth of 30 cm (Figure 20). This depth is satisfactory because more than 75% of soil organic carbon, as well as plant roots in drylands are known to be concentrated within this depth (Sileshi 2016, 3). This method maximizes the information gathered within the sample, and likely provides accurate data. In the case of the village of Mogodin, two mature trees other than *Faidherbia albida* were used because there were no *Faidherbia albida* trees. In addition, a probe thermometer recorded soil surface (first top 3cm depth of soil) temperature under tree canopy, and fifteen and thirty meters away from it in a clear area (Image 7). Additionally, I took in each village a first sample and a second sample at fifteen meters from the first sample in areas without trees on cropland. I did not use this data in my analysis because it did not allow a proper comparison with the data collected from the group-based samples.

Image 5. Soil sampling illustration

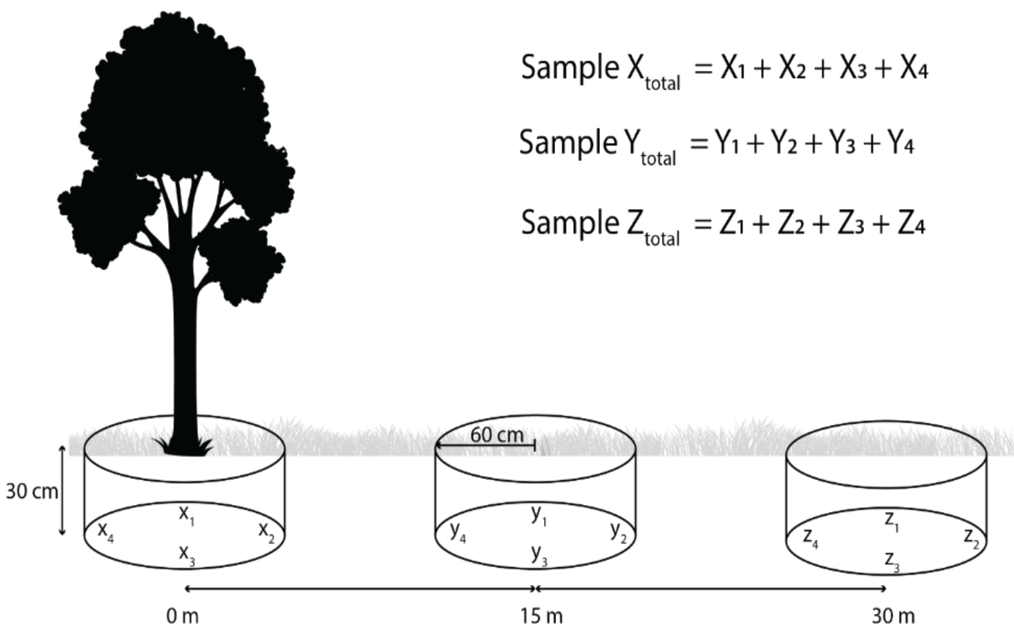

Figure 20. Soil sampling method

Designed by brgfx / Freepik

Image 6. Faidherbia albida tree in the fields of Safi during the rainy season (July)

Image 7. Temperature recording

The National Soils Office, which is the government agency of soils in Burkina Faso, analyzed the soil samples collected in the field. This agency produced soil composition data for the variables used in this study, which are nitrogen, carbon, organic matter, total exchangeable base cations, base saturation, cation-exchange capacity, and potential of hydrogen. I selected these variables based on the literature review, as well as feedback from committee members and agents from the National Soils Office. To test the null hypothesis, I used R software to analyze the data produced by the National Soils Office by performing a repeated-measure analysis of variance (ANOVA). ANOVA identifies differences in the means of three or more groups. ANOVA evaluates the variability of the means between the group or category, and “the variability within each group around the group mean” (McGrew and Monroe 2000, 147). The null hypothesis is rejected if “the variability between the group means is relatively large as contrasted with a relatively small amount of variability within each group around its group mean" (McGrew and Monroe 2000, 147). To test the null hypothesis for each variable in this study, I used ANOVA to analyze the data based on the site (village), the distance (under tree, 15m and 30m away from tree trunk), and the type of tree (*Faidherbia albida,* and other tree species). For p-values (probability of rejecting the null hypothesis when it is true [McGrew and Monroe 2000, 121]) less than 0.05, we reject the null hypothesis for the alternative hypothesis. In this case, a Tukey's post-hoc test is performed to identify the groups that have different means because ANOVA simply determines if there is at least one group that is significantly different from other groups. Overall, the hypotheses used in this research are:

- ❖ H_0 (null hypothesis): there is no group with a mean that is statistically different from other groups.
- ❖ H_1 (alternative hypothesis): there is at least one group with a mean that is statistically different from other groups.

The figure below summarizes the sampling process.

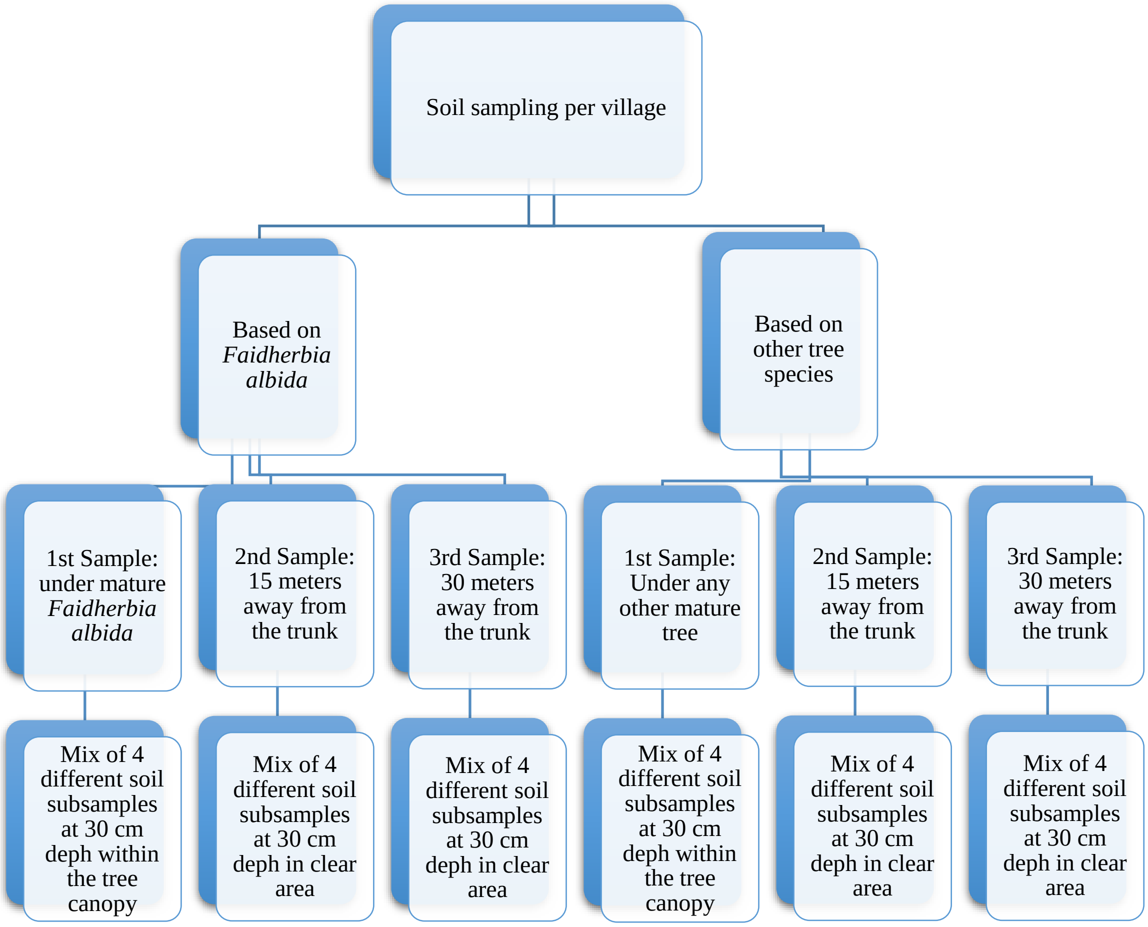

Figure 21. Summary of the sampling process

To conclude, I conducted the field work during the rainy season, which is when most agricultural production activities happen in Burkina Faso. "Burkina Faso agriculture is dominated by 75% of rainfed crop production" (Traore 2007, abstract). Conducting field work during this season allowed me to see how farmers manage and protect new stems (Image 8) while growing crops. On the other hand, floodable roads made the access to villages and croplands more challenging. NGO representatives facilitate data collection because farmers were aware of the research before the interviews and a meeting time was arranged according to their availability.

Image 8. New stem protection example

CHAPTER 4: RESULTS

This chapter shows the biophysical and socioeconomic impacts of farmer managed natural regeneration in the Nord Plateau Mossi. Specifically, this chapter presents the results of how trees influence soil fertility based on the analysis of soil samples from the study area. Additionally, I will discuss the changes induced by FMNR in terms of access to firewood, variety of food, and income in this section.

4.1 Biophysical Impacts of Farmer Managed Natural Regeneration

4.1.1 Impact on Soil Fertility

Soil fertility is “the capacity to receive, store and transmit energy to support plant growth” (FAO 2020b). In other words, it is the capacity of the soil to provide the nutrients essential to support plant growth (SSSA 2020). There are three components to soil fertility: the physical component (soil structure, soil temperature, clay content, water retention, and aeration), the chemical component (macronutrients, micronutrients, soil pH, and soil organic matter), and the biological component (bacteria, fungi, and plant roots) (Franzlubbers and Haney 2006, 8). This study measured soil fertility using soil carbon, organic matter, nitrogen, potential of hydrogen (pH), total exchangeable base cations (TEBC), cation-exchange capacity (CEC), and base saturation (BS) with the following results.

- Carbon

Soil carbon contributes to soil fertility by influencing three mechanisms. It improves plant available water holding capacity, increases supply the of nutrients, and enhances soil structure and other physical properties (Lal 2006, 198). The following table provides a summary of the analysis of carbon content from all soil samples using ANOVA (Table 3). The analysis identified no statistical difference in the mean carbon value between villages (p-values were higher than 0.05), as well as between *Faidherbia albida* trees and other tree species; however, analyzing carbon content based on the distance at which the soil samples were taken, p-value is less than 0.05. This means that at least one group (under tree, 15m or 30m away from tree trunk) have a mean that is significantly different from other groups. Tukey's post-hoc test identified the group or groups that are statistically different (Table 4).

Table 3. Carbon content analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	0.0352	0.00879	0.219	0.925
	Residuals	25	1.0014	0.04006	-	-
Type	Factor (Tree group)	1	0.0199	0.01991	0.548	0.465
	Residuals	28	1.0167	0.03631	-	-
Distance	Factor (Sampling distance)	2	0.2269	0.11345	3.783	0.0356
	Residuals	27	0.8097	0.02999	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05; Green color = p-value ‹ 0.05

Table 4. Tukey's post-hoc test of carbon content based on distance

Tukey multiple comparisons of means				
95% family-wise confidence level				
	diff	lwr	upr	p adj
b-a	-0.1639	-0.35591	0.0281174	0.1053166
c-a	-0.1998	-0.39181	-0.0077825	0.0401826
c-b	-0.0359	-0.22791	0.1561174	0.8887857

Key: a = under tree; b = 15m away from tree; c = 30m away from tree; diff = difference in the observed means; lwr = lower end point of the interval; upr = upper end point of the interval; p adj = p-value after adjustment; Green color = p-value ‹ 0.05

Although the mean and median carbon values decreased farther from trees (under diff in Table 4**Error! Reference source not found.**, Figure 22), Tukey's post-hoc test shows that there is only one significant difference in this case, which is between the means of group a and group c. The p-value between group a (under tree) and group c (30m away from tree) is less than 0.05. We can then conclude that carbon content decreases significantly from under trees to 30m away from them in our study area. Figure 23 presents the plot of the results obtained from Tukey's post-hoc test on carbon content.

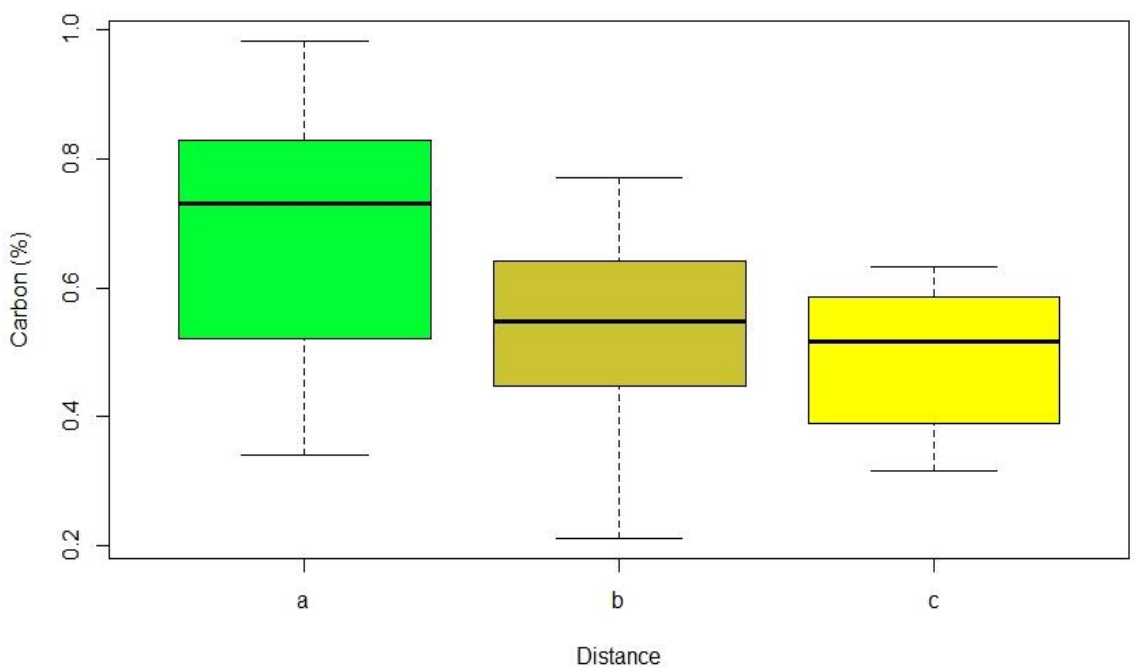

Figure 22. Boxplot of carbon distribution based on distance

Key: a = under tree; b = 15m away from tree; c = 30m away from tree

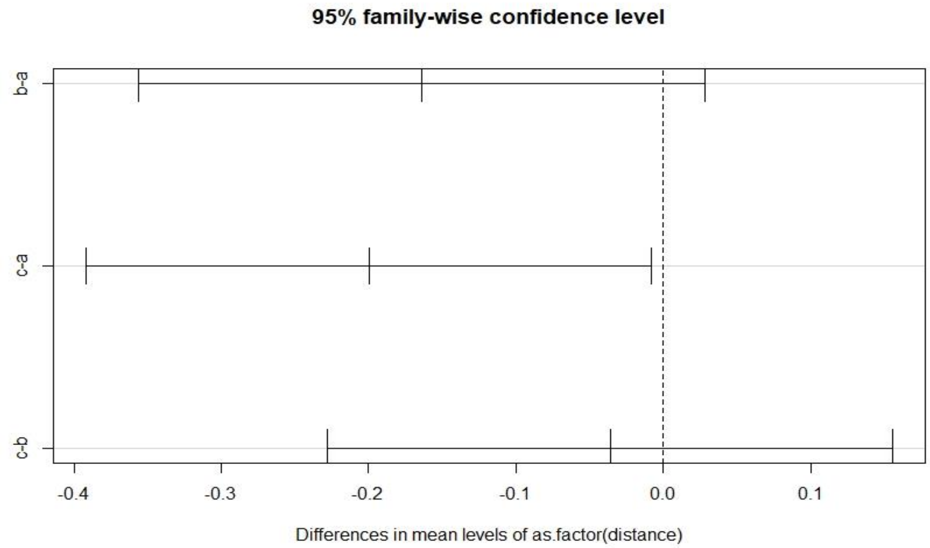

Figure 23. Plot of Tukey's post-hoc test on carbon based on distance

Key: x axis = Differences in carbon mean levels

- Organic matter

Soil organic matter plays an important role in providing a suitable physical environment for plant growth. Organic matter influences "soil aggregation which in turn influences water infiltration, moisture content, drainage, tilth, aeration, temperature, microbial activities, and root penetration" (Allison 1973, 315). The following tables provide the results of the analysis of variance of organic matter from the soil samples.

Table 5. Organic matter content analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	0.1044	0.0261	0.219	0.925
	Residuals	25	2.9765	0.1191	-	-
Type	Factor (Tree group)	1	0.0593	0.0593	0.549	0.465
	Residuals	28	3.0216	0.1079	-	-
Distance	Factor (Sampling distance)	2	0.6746	0.3373	3.785	0.0356
	Residuals	27	2.4063	0.0891	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05; Green color = p-value ‹ 0.05

Table 6. Tukey's post-hoc test of organic matter content based on distance

Tukey multiple comparisons of means				
95% family-wise confidence level				
	diff	lwr	upr	p adj
b-a	-0.2826	-0.61362	0.048423	0.1052418
c-a	-0.3445	-0.67552	-0.013476	0.0401430
c-b	-0.0619	-0.39292	0.269123	0.8887483

Key: a = under tree; b = 15m away from tree; c = 30m away from tree; diff = difference in the observed means; lwr = lower end point of the interval; upr = upper end point of the interval; p adj = p-value after adjustment; Green color = p-value ‹ 0.05

Compared to the analysis of variance of carbon, the results from ANOVA in this case indicate that we can reject the null hypothesis based on distance (Table 5). In other words, there is at least one group with a mean statistically different from other groups. Based on the results from Tukey's post-hoc test (Table 6, Figure 24), we can conclude that there is a significant difference in the mean content of organic matter under trees and at 30m away from them with a decrease of organic matter the farther away from the tree (Figure 25).

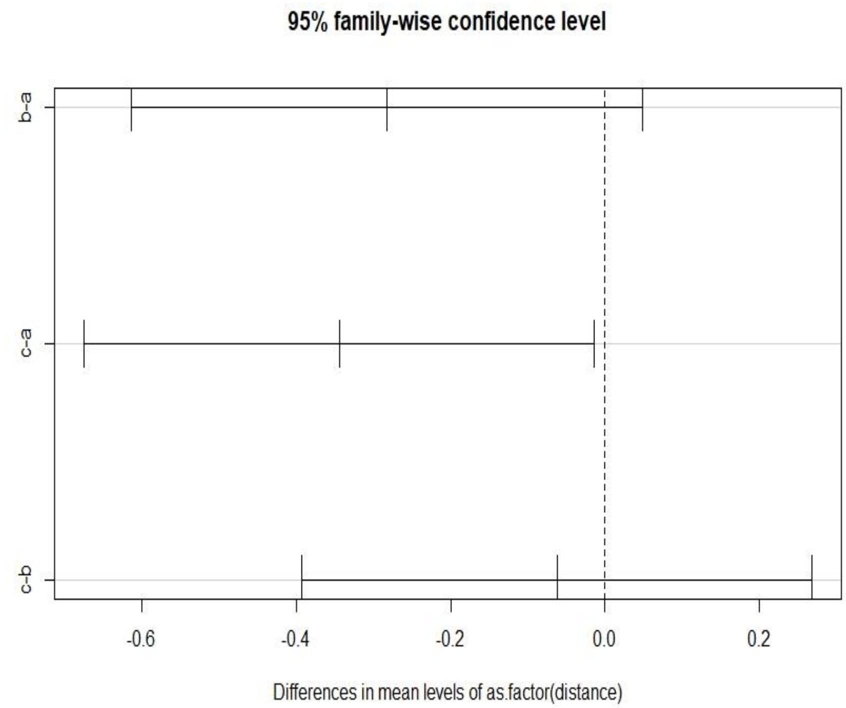

Figure 24. Plot of Tukey's post-hoc test on organic matter based on distance

Key: x axis = Differences in organic matter mean levels

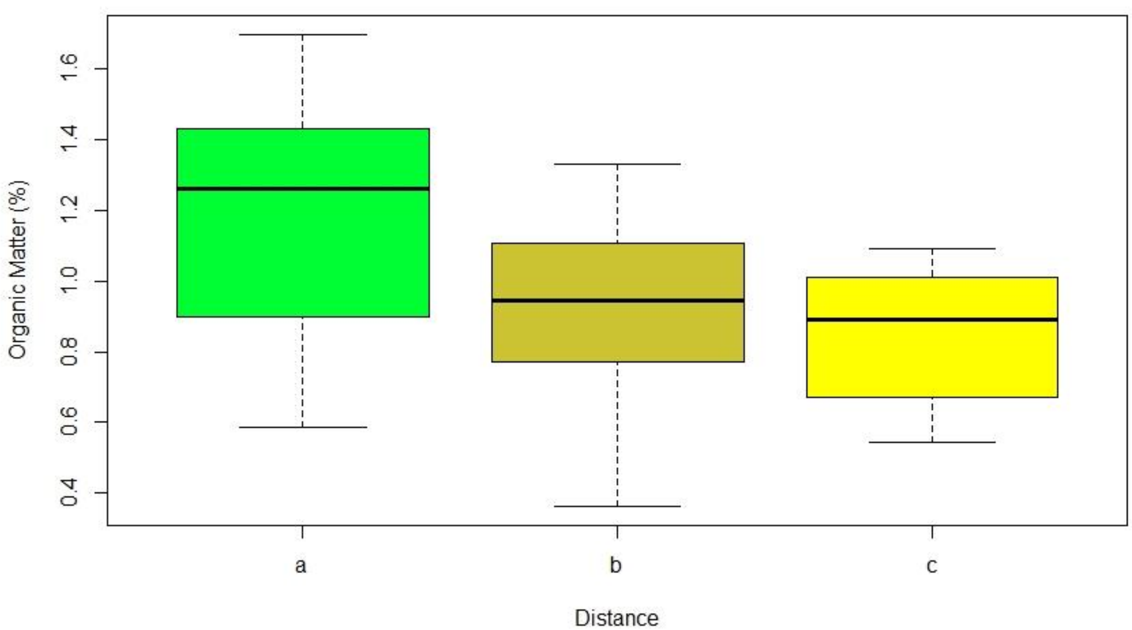

Figure 25. Boxplot of organic matter distribution based on distance

Key: a = under tree; b = 15m away from tree; c = 30m away from tree

- Nitrogen

Nitrogen is a key component of plant growth. It is a constituent of proteins, enzymes, chlorophyll, and deoxyribonucleic acids involved in the synthesis of plant substances. Its abundance can be observed through the appearance of leaves. A deep green (healthy appearance) is an indication of an abundant nitrogen supply and a light green color, which is usually associated with dwarfed growth and possibly dying older leaves, could indicate a deficiency in nitrogen (Allison 1973, 461). The results from the analysis of nitrogen content in the study area are presented in the following tables.

Table 7. Nitrogen content analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	0.00030	0.000076	0.199	0.937
	Residuals	25	0.00956	0.000382	-	-
Type	Factor (Tree group)	1	0.00039	0.000399	1.18	0.287
	Residuals	28	0.00946	0.000338	-	-
Distance	Factor (Sampling distance)	2	0.00265	0.001328	4.974	0.0145
	Residuals	27	0.00720	0.000267	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05; Green color = p-value ‹ 0.05

Table 8. Tukey's post-hoc test of nitrogen content based on distance

Tukey multiple comparisons of means				
95% family-wise confidence level				
	diff	lwr	upr	p adj
b-a	-0.0190	-0.037118	-0.0008819	0.0384325
c-a	-0.0208	-0.038918	-0.0026819	0.0220054
c-b	-0.0018	-0.019918	0.0163180	0.9671450

Key: a = under tree; b = 15m away from tree; c = 30m away from tree; diff = difference in the observed means; lwr = lower end point of the interval; upr = upper end point of the interval; p adj = p-value after adjustment; Green color = p-value ‹ 0.05

The above table presents a p-value of 0.0145 for the analysis of variance of nitrogen based on distance (Table 7). This means that in this case, the null hypothesis is rejected. In other words, there is a significant difference in the nitrogen mean value under trees versus samples taken 30m away from them. This difference is confirmed by Tukey's post-hoc test (Table 8, Figure 26). There is a significant difference in nitrogen mean value comparing nitrogen content under trees to nitrogen content at 15m away from trees. This significance is also noticed between nitrogen content under trees and its content at 30m away from trees. In addition, the nitrogen mean value decreased the farther we move away from trees. Nitrogen median value decreased from under trees to 15 m away from them, then slightly increased from 15 m to 30 m away from trees (Figure 27). Although the literature distinguished *Faidherbia albida* as a nitrogen-fixing tree, in our case we did not find any significant difference in soil nitrogen content under *Faidherbia albida* trees compared to other tree species.

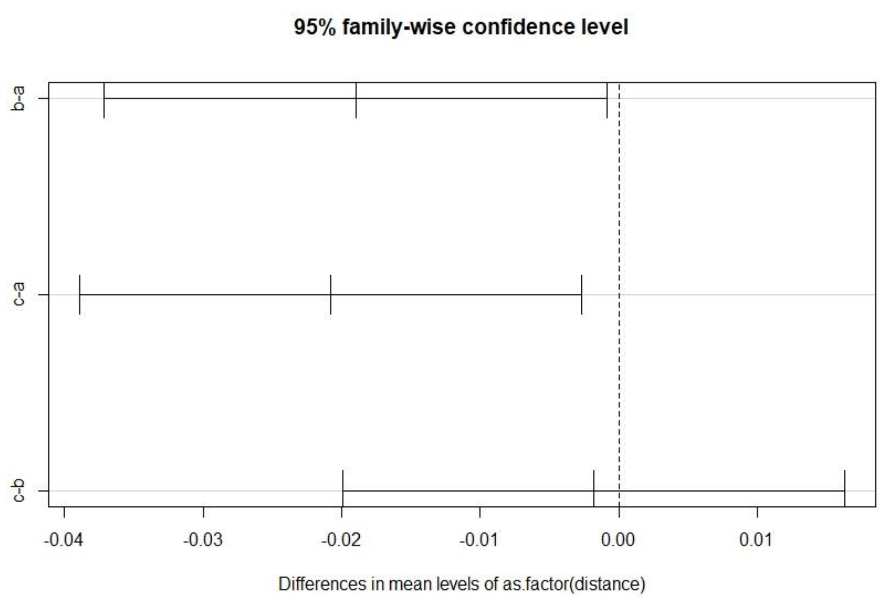

Figure 26. Plot of Tukey's post-hoc test on nitrogen based on distance

Key: x axis = Differences in nitrogen mean levels

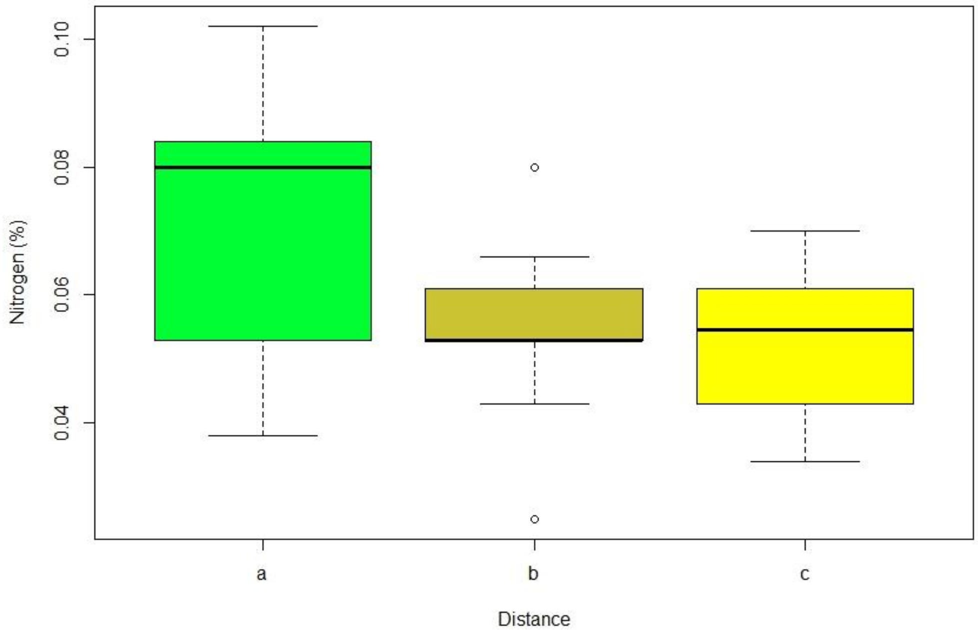

Figure 27. Boxplot of nitrogen distribution based on distance

Key: a = under tree; b = 15m away from tree; c = 30m away from tree

➢ Potential of hydrogen

Soil pH refers to how acidic or alkaline the soil is. Its scale ranges from 0 to 14, 7 is neutral. The soil is basic or alkaline if the pH is greater than 7 and acidic if it is less than 7. Most crops grow well with a pH between 6 and 7.5. Soil forming factors define natural soil pH, however, agriculture and weathering can lead to important changes in soil pH. The removal of cations by crops, leaching, the effect of fertilizers and amendments, and the variations in organic matter content and soil buffering capacity all can change the soil potential of hydrogen (US Natural Resources Conservation Service 2011). In this study, we analyzed soil pH using ANOVA; however, the results reveal that we fail to reject the null hypothesis (Table 9). In other words, there is no significant difference in pH mean values based on the villages, tree species, or distance; however, it is important to note that pH values vary between 5.1 and 6.56 in the study area (Table 10).

Table 9. pH value analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	0.7154	0.1788	1.664	0.19
	Residuals	25	2.6874	0.1075	-	-
Type	Factor (Tree group)	1	0.3034	0.3034	2.741	0.109
	Residuals	28	3.0994	0.1107	-	-
Distance	Factor (Sampling distance)	2	0.134	0.06696	0.553	0.582
	Residuals	27	3.269	0.12107	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05

Table 10. pH value range per village

Village	pH
Boala	5.1 - 5.97
Kaoukouagin	5.86 - 6.24
Mogodin	5.15 - 6.01
Safi	5.17 - 6.56
Tema	5.34 - 5.79

- Total exchangeable base cations (TEBC)

Total exchangeable base cations are defined as “the most prevalent, exchangeable and weak acid cations in the soil” (Lövblad, Tarrason and Tørseth n.d., 73). In this study, TEBC includes calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), potassium ions (K^{+}), and sodium ions (Na^{+}). These cations are important for the translocation of carbohydrates; regulation of absorbed and released water during transpiration; and cell growth, protein synthesis, and transfer of energy within the plant (University of Hawai‘i 2020). The following tables present the results from the base cations analysis.

Table 11. Exchangeable base cations content analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	184.86	46.22	54.66	5.33E-12
	Residuals	25	21.14	0.85	-	-
Type	Factor (Tree group)	1	0.12	0.118	0.016	0.9
	Residuals	28	205.88	7.353	-	-
Distance	Factor (Sampling distance)	2	2.47	1.236	0.164	0.85
	Residuals	27	203.52	7.538	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05; Green color = p-value ‹ 0.05

Table 12. Tukey's post-hoc test of exchangeable base cations content based on site

Tukey multiple comparisons of means				
95% family-wise confidence level				
	diff	lwr	upr	p adj
K-B	5.845	4.2859476	7.4040524	0.0000000
M-B	0.5716	-0.9873857	2.1307190	0.8165040
S-B	-0.76	-2.3190524	0.7990524	0.6139194
T-B	-0.7483	-2.3073857	0.8107190	0.6273846
M-K	-5.273	-6.8323857	-3.7142810	0.0000000
S-K	-6.605	-8.1640524	-5.0459476	0.0000000
T-K	-6.593	-8.1523857	-5.0342810	0.0000000
S-M	-1.3316	-2.8907190	0.2273857	0.1207029
T-M	-1.32	-2.8790524	0.2390524	0.1259305
T-S	0.0116	-1.5473857	1.5707190	0.9999999

Key: B = Boala; K = Kaoukouagin; M = Mogodin; S = Safi; T = Tema; diff = difference in the observed means; lwr = lower end point of the interval; upr = upper end point of the interval; p adj = p-value after adjustment; Green color = p-value ‹ 0.05

Exchangeable base cations content analysis reveals that there is at least one group that is significantly different from other groups based on the sites (Table 11). The Tukey's post-hoc test shows that TEBC mean value in the village of Kaoukouagin is significantly different from all other villages (Table 12, Figure 28). In addition, the test also reveals that base cations mean value in the village of Kaoukouagin is higher than its mean value in the other four villages (Figure 29). In other words, Kaoukouagin's soil has more Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} than Mogodin, Safi, and Tema. This result is confirmed by the TEBC value range per village in the following table (Table 13).

Table 13. TEBC value range per village

Village	TEBC (meq/100)
Boala	2.26 - 3.19
Kaoukouagin	7.19 - 9.45
Mogodin	1.56 - 4.82
Safi	0.95 - 3.34
Tema	1.4 - 2.49

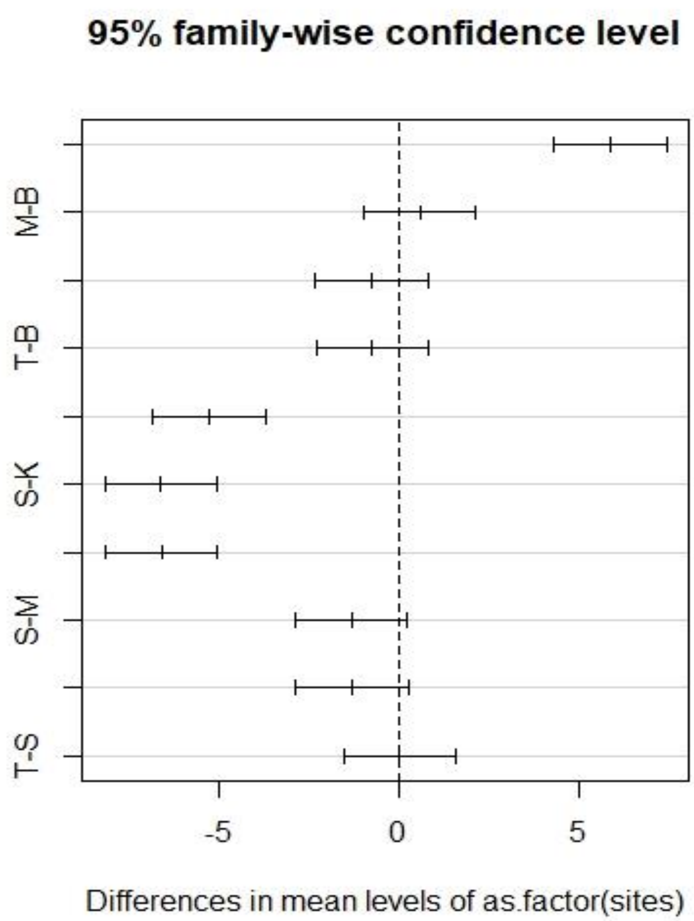

Figure 28. Plot of Tukey's post-hoc test on TEBC based on site

Key: x axis = Differences in TEBC mean levels

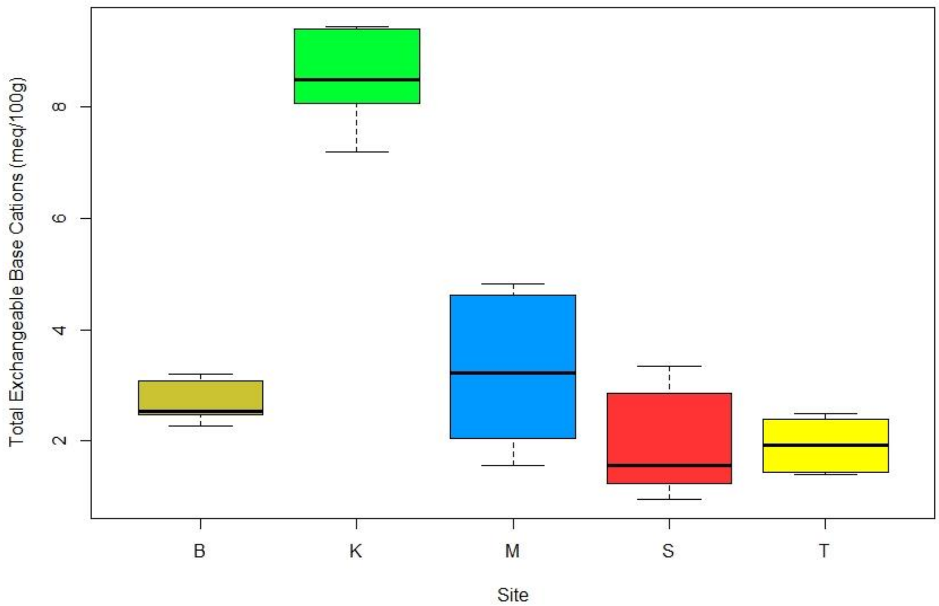

Figure 29. Boxplot of TEBC distribution based on distance

Key: B = Boala; K = Kaoukouagin; M = Mogodin; S = Safi; T = Tema

- Cation-exchange capacity (CEC)

Cation-exchange capacity measures soil's ability to hold exchangeable cations (Brown and Lemon 2020). CEC is important for field water capacity and biological regulation, as well as for the overall nutrient dynamics in the soil (Deumlich, Thiere, and Altermann 2015, 768). Soils with high CEC have a better water holding capacity and have more clay and organic matter than soils with low CEC (Figure 30). In contrary, soils with low CEC will likely develop cation deficiency and be more susceptible to leaching (CUCE 2007, 2). This study used calcium ions, magnesium ions, potassium ions, and sodium ions to calculate cation-exchange capacity for each village (Table 14). The CEC value ranged from 1.86 to 16.45 milliequivalents per 100 grams (meq/100 g). Cation-exchange capacity content analysis (Table 15) shows the results obtained from the analysis of variance of CEC. Based on these results, we reject the null hypothesis when analyzed based on the site. In other words, there is at least one village with a CEC mean value significantly different from other villages. The interpretation of the results from Tukey's post-hoc test (Table 16) shows that Kaoukouagin clearly presents a higher mean value of cation-exchange capacity compare to the other villages (Figure 31, Figure 32).

Table 14. CEC value range per village

Village	CEC (meq/100)
Boala	4.16 - 4.71
Kaoukouagin	10.15 - 16.45
Mogodin	2.82 - 6.74
Safi	1.86 - 4.72
Tema	2.28 - 3.68

Table 15. Cation-exchange capacity content analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	473	118.25	60.43	1.74E-12
	Residuals	25	48.9	1.96	-	-
Type	Factor (Tree group)	1	0.4	0.367	0.02	0.889
	Residuals	28	521.6	18.627	-	-
Distance	Factor (Sampling distance)	2	4.8	2.396	0.125	0.883
	Residuals	27	517.1	19.153	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05; Green color = p-value ‹ 0.05

Table 16. Tukey's post-hoc test of cation-exchange capacity content based on site

Tukey multiple comparisons of means				
95% family-wise confidence level				
	diff	lwr	upr	p adj
K-B	9.14	6.768007	11.5119926	0.0000000
M-B	0.17	-2.201993	2.5419926	0.9995311
S-B	-1.3583	-3.730326	1.0136592	0.4625282

T-B	-1.4083	-3.780326	0.9636592	0.426975
M-K	-8.97	-11.34199	-6.5980074	0.0000000
S-K	-10.4983	-12.87033	-8.1263408	0.0000000
T-K	-10.5483	-12.92033	-8.1763408	0.0000000
S-M	-1.5283	-3.900326	0.8436592	0.3471243
T-M	-1.5783	-3.950326	0.7936592	0.3165216
T-S	-0.05	-2.421993	2.3219926	0.9999964

Key: B = Boala; K = Kaoukouagin; M = Mogodin; S = Safi; T = Tema; diff = difference in the observed means; lwr = lower end point of the interval; upr = upper end point of the interval; p adj = p-value after adjustment; Green color = p-value ‹ 0.05

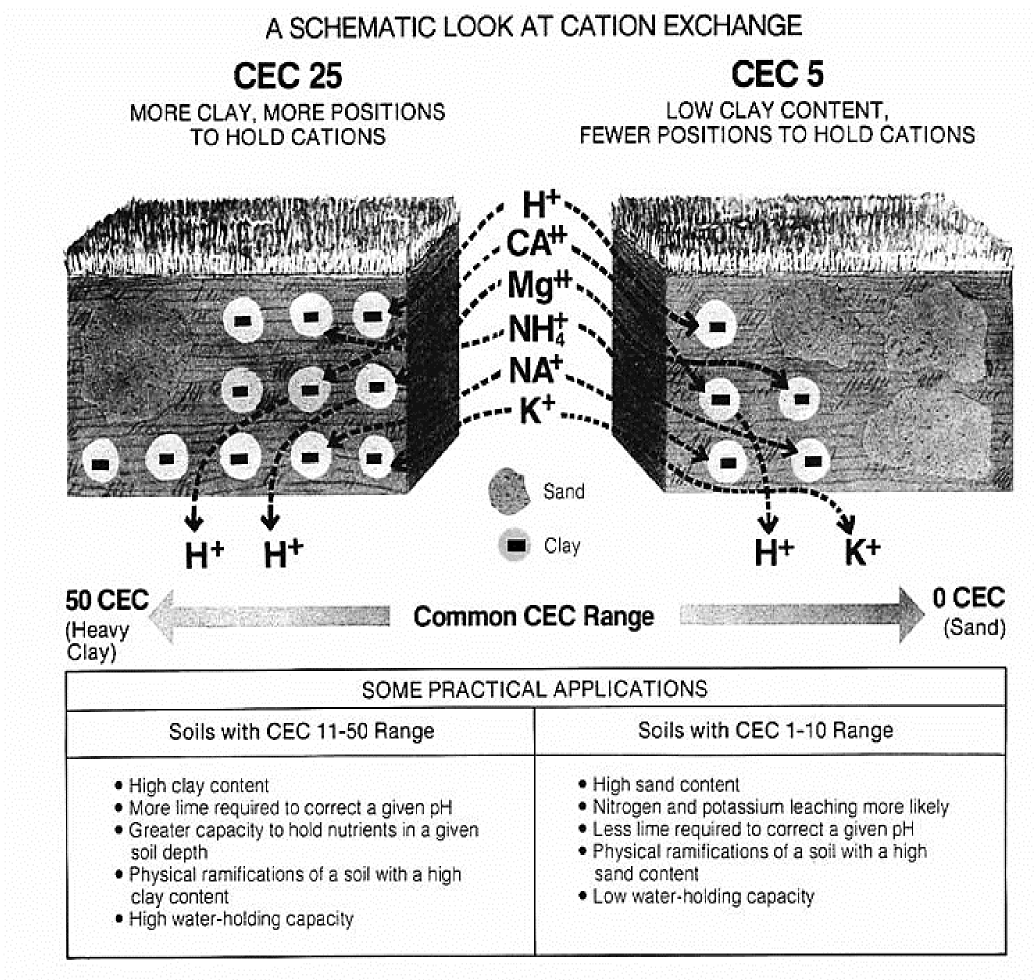

Figure 30. CEC range with associated applications.

Source: Spectrum Analytic Inc, 2020.

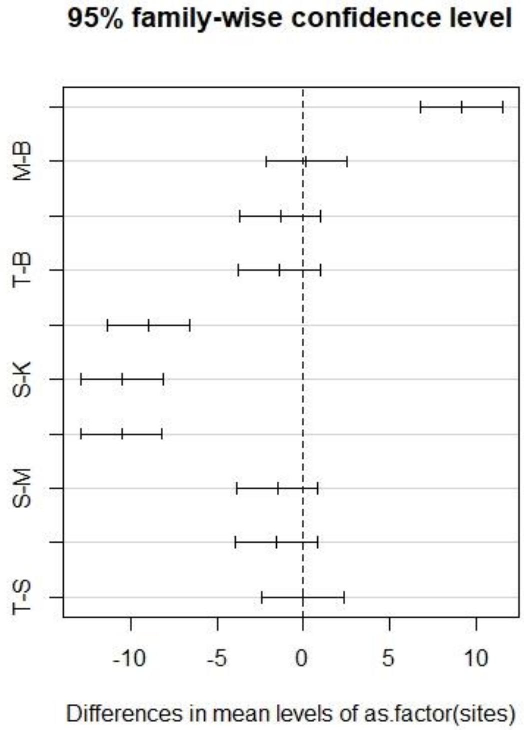

Figure 31. Plot of Tukey's post-hoc test on CEC based on site

Key: x axis = Differences in CEC mean levels

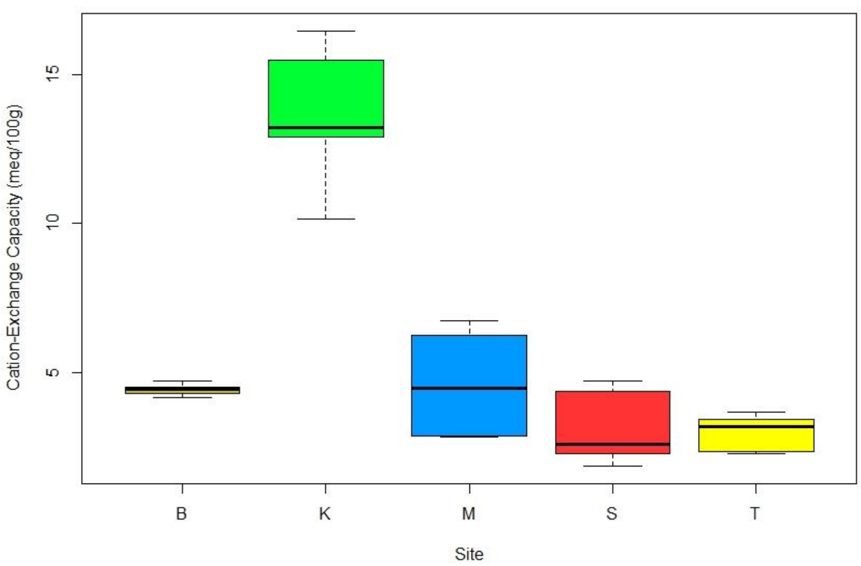

Figure 32. Boxplot of CEC distribution based on distance

Key: B = Boala; K = Kaoukouagin; M = Mogodin; S = Safi; T = Tema

- Base saturation (BS)

Base saturation is the percentage of CEC occupied by base cations (Culman, Mann, and Brown 2020). Soils with high BS are more fertile than soils with low BS because they have a higher pH and are more preserved against acid cations. Additionally, they present nearly no aluminum cations (Al^{3+}), which are toxic to plant growth and have more available base cations for plant use (Figure 33; Sonon, Kissel, and Saha 2017, 3). This study used the following formula to calculate BS:

Base Saturation (%) = (Base cations/CEC) x 100

Base Saturation (%) = $(Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}/CEC) \times 100$

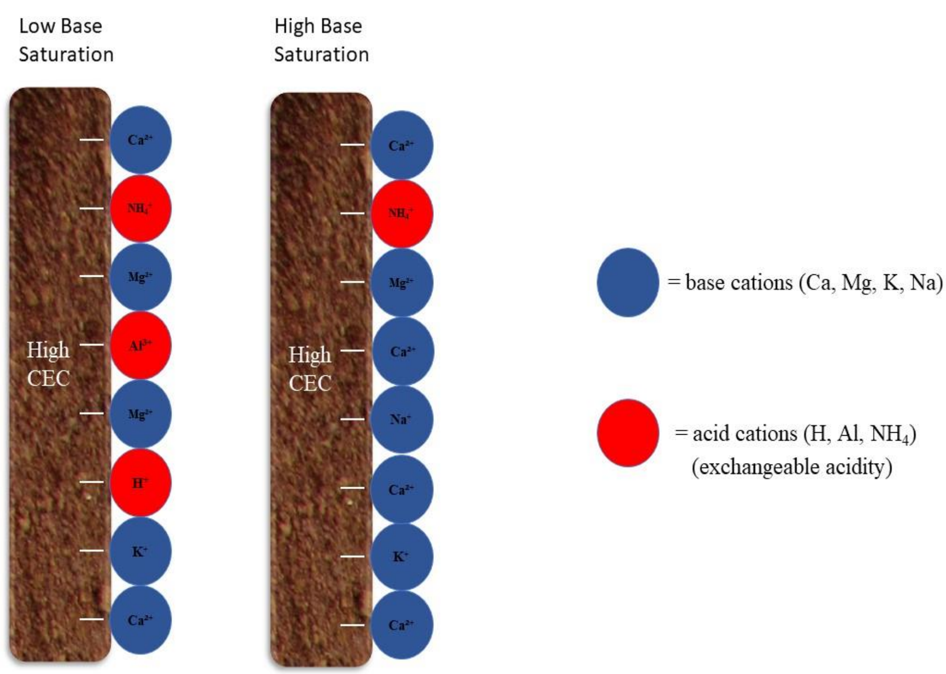

Figure 33. Soil with differences in base saturation.

Source: Adapted from Culman, Mann, and Brown 2020

The following table provides the results of our analysis of BS in the study area.

Table 17. Base saturation analysis

		Df	Sum Sq	Mean Sq	F value	P value
Site	Factor (Village)	4	300.9	75.22	1.516	0.228
	Residuals	25	1240.5	49.62	-	-
Type	Factor (Tree group)	1	3.8	3.76	0.068	0.796
	Residuals	28	1537.6	54.91	-	-
Distance	Factor (Sampling distance)	2	92.9	46.43	0.866	0.432
	Residuals	27	1448.5	53.65	-	-

Key: Df = degrees of freedom; Sum Sq = sums of squares; Mean Sq = mean squares; Red color = p-value › 0.05

Based on the results from the analysis of variance (Table 17), we fail to reject the null hypothesis in all factors. There is no group with a BS mean value that is statistically different from other groups in our study area. The table below (Table 18) shows the range of BS values in the study area per village.

Table 18. BS range in study area per village

Village	BS (%)
Boala	51 - 68
Kaoukouagin	57 - 71
Mogodin	55 - 77
Safi	51 - 71
Tema	54 - 73

4.1.2 Impact of Obtaining Firewood

Burkina Faso, as well as most sub-Saharan countries, heavily relies on firewood as a main source of energy. Firewood plays a key role in household energy supply in both rural and urban areas. Burkina Faso’s dependency on firewood is expected to increase because of a high annual population growth rate combined with high expenses associated with other energy sources, which are scarce (Arevalo 2016, 1399). The 2006 census revealed that firewood is the main source of energy for cooking for 88% of all households in Burkina Faso (Bensch et al. 2013, 6). Total firewood consumption increased 76% from 2008 to 2017 (Figure 34). This high demand of firewood is no exception in our study area, and FMNR plays an important role in the obtaining of firewood.

Respondents from focus groups viewed farmer managed natural regeneration as one of the main sources of firewood for households, which also reduced the burden of collecting firewood for women. Noopoko[1], a woman from Mogodin, revealed that women collect firewood from dead branches in their croplands, which they use to assemble bundles of firewood near their habitations. She also specified that being able to assemble bundles of firewood is important for them, because it can be difficult to collect firewood, especially during the rainy season. Additionally, she stated that having trees nearby allows them to accumulate bundles of firewood near their houses therefore when it is rainy, they only need to take the quantity necessary to prepare the household meal from the bundles to their kitchens (Image 9). On special occasions such as weddings and funerals, they collect more firewood from trees than usual to brew the local beer called "ran-moaga" or "dolo", and to cook enough food to feed the attendees.

[1] All focus groups were confidential; the names of the interviewees are withheld by mutual agreement and replaced with aliases.

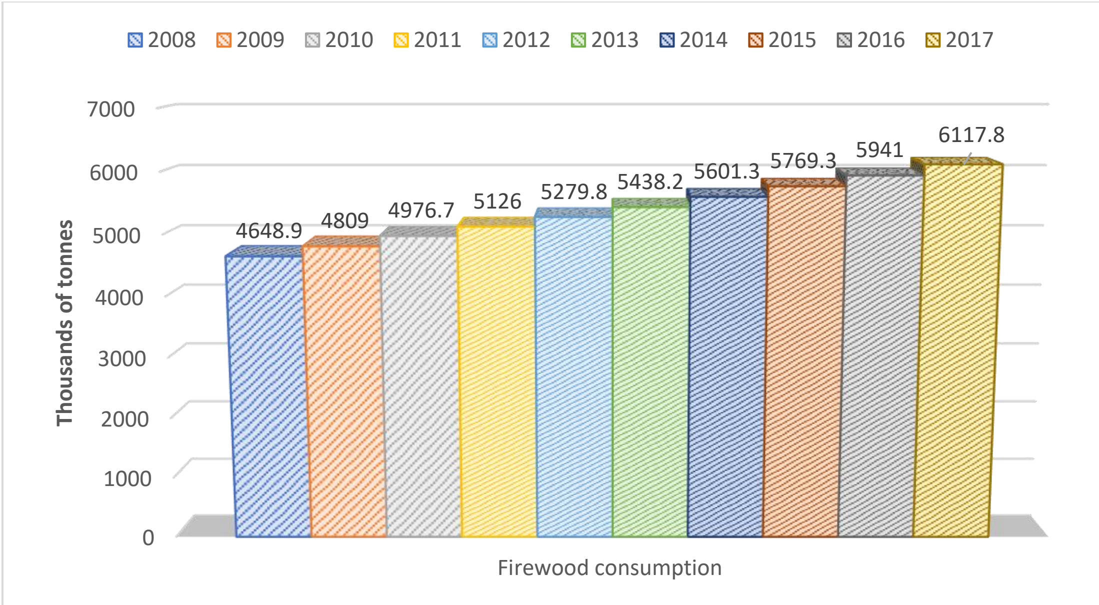

Figure 34. Firewood consumption in Burkina Faso from 2008-2017

Source: General Direction of Renewable Energies. Adapted from Direction Générale des Etudes et des Statistiques Sectorielles 2018

Image 9. Bundle of firewood

4.2 Socioeconomic Impact of Farmer Managed Natural Regeneration

Respondents from the focus groups suggested that FMNR has positive socioeconomic impacts on farmers lives. First, FMNR contributes to increasing household discretionary income. Discretionary income refers to “an individual’s income that is available for spending after all essentials (such as food and accommodation) have been paid for” (Dolnicar et al. 2008, 45). FMNR adds to discretionary income because it saves households 7 to 14 USD per bundle of firewood (based on market price) by providing free bundles of firewood from tree branches. Additionally, firewood is not sold for cash. Each bundle lasts on average one-and-a-half months. Firewood is the main source of energy, so it is essential for the proper functioning of households. The money saved on obtaining firewood can be spent in other household expenses.

Additionally, sales of shea nuts (Image 10) extracted from the fruits of *Vitellaria paradoxa*, or shea tree (Image 11), contributes 25 to 72 USD to household income per year. Income is the net total monetary payments received in a given period (Encyclopedia Britannica, s.v. “income” [accessed May 21, 2020, https://www.britannica.com/topic/income]). Nooraogo, a farmer from Mogodin, highlighted the value added to household income from the sales of shea nuts by revealing that in his village “the sales from shea nuts allowed many households to provide for their needs”. Other researchers also highlighted FMNR contributions to household income (e.g. Reij and Winterbottom 2015; Reij, Tappan, and Smale 2009b; Weston et al. 2015).

Image 10. Illustration of collected shea nuts.

Source: van den Brink 2019.

Image 11. Fruits from the shea tree (Vitellaria paradoxa)

Second, respondents stated that FMNR provides various food products to households (Table 19). From the 12 food groups used in the research, each food group has a score of 1 if it was consumed in the household or 0 if not. Households in the study area have a household dietary diversity score of 5. In other words, households have access to five of the twelve food groups in the study area. FMNR increases household access to a variety of foods by providing fruits, tree leaves used as vegetables, and cooking oil, which is extracted from shea nuts. In other words, FMNR plays an important role in household access to a variety of foods, because it provides 3 of the 5 food groups consumed within the household. Throughout the year, tree products are consumed in the household based on available tree species depending on the season.

Table 19. Household dietary diversity score in study area

Food group	Score
Cereals	1
White roots and tubers	0
Vegetables (tree leaves)	1
Fruits	1
Meat	0
Eggs	0
Fish and seafood	0
Legumes, nuts, and seeds	0
Milk and milk products	0
Oils and fats (cooking oil extracted from shea nuts)	1
Sweets	0
Spices, condiments, and beverages	1
Total score	5

Key: Green color = food group provided by trees

Third, respondents stated that they use trees to provide medicine. For example, tree leaves, bark, branches, or roots are used to treat illnesses or pains ranging from wounds, upset stomach, headaches, to diarrhea, fatigue, and so forth. Women also use infusions of certain parts of the trees during and after pregnancy to either prepare for childbirth, relieve pain during childbirth, or protect the newborn against some diseases. Adjara, a woman from Mogodin, added that “when a woman gives birth, the first medicine that will give her strength always comes from a tree. It can be an infusion of leaves or bark, but it always comes from a tree”.

Finally, FMNR plays a key role in agricultural production. Some respondents claimed that trees reduce wind speed, because they noticed that their habitations are less damaged by winds compare to where there are no trees. Wendyam, a farmer from Boala also explained that “when there are no trees in the croplands, crops do not last long because the wind will destroy them, however, when there are trees the effect of the wind is reduced, and it helps crop growth”.

Additionally, Pegdwende, another farmer from Mogodin, added that “as rainfall decreases, soils are more humid and easy to cultivate where there are trees”. Temperature data collected in the field supports this claim, because temperatures were higher outside the tree canopy in all sampling sites compared to within the tree canopy (Table 20). Less evaporation is likely to occur within the tree canopy compared with clear areas.

Furthermore, respondents stated that tree leaves fertilize croplands when they fall, are used to make compost (Image 12), and protect croplands from sunlight. Also, tree branches are used as poles for constructing granaries (Image 13), and fences to protect croplands from livestock (Image 14).

Table 20. Soil temperature data

Village	Average Temperature (°C)		
	Under trees	15m away from trees	30m away from trees
Boala	27.35	32.7	33.2
Kaoukouagin	28.5	35.1	35.4
Mogodin	27.25	34.7	36.95
Safi	27.1	33.65	33.4
Tema	25	30.6	30.3

Image 12. Compost pit example (leaves are underneath and covered with plant residue)

Image 13. Granaries

Image 14. Illustration of tree branches used as fence

The following table summarizes the trees mentioned by respondents in the focus groups with their use (Table 21).

Table 21. Trees mentioned by respondents with their use

Name		Use
Moré	Scientific	
Bagande	*Piliostigma reticulatum*	Medicine, feed livestock, and construction
Baghen nyaga	*Piliostigma thonningii*	Medicine
Bangande	*Bauhinia rufescens*	Medicine
Gompelaga	*Acacia seyal*	Feed livestock
Gumiiga	*Acacia seyal*	Feed livestock
Kalnyaka	*Combretum micranthum*	Food
Kanga	*Combretum micranthum*	Medicine
Karemtouga	*Combretum nigricans*	Food
Katempuanga	*Strychnos spinosa*	Food
Kielega	*Balanites aegyptiaca*	Food and soap making
Kiesgha	*Maerua crassifolia*	Medicine
Mugulanga	*Ziziphus mauritiana*	Medicine and food
Muguninga	*Ziziphus mucronata*	Medicine and food
Neem	*Azadirachta indica*	Medicine
Poutrepouga	*Calotropis procera*	Medicine
Pusga	*Tamarindus indica*	Medicine, food, and sale
Siibiga	*Lannea microcarpa*	Medicine and food
Taanga	*Vitellaria paradoxa*	Medicine, food, and sale
Toega	*Adansonia digitata*	Medicine and food
Wilimwiiga	*Guiera senegalensis*	Medicine
Zilogo	*Cadaba farinosa*	Food

4.3 Negative Impact

Although FMNR offers multiple benefits, I recorded a negative side to it from the focus groups. The interviews revealed that FMNR can be source of tensions within the community. Because FMNR is a farmer-led initiative, farmers are not bound to protect trees, especially when they are still at the early phase (new stems). When trees have grown enough to provide benefits (fodder for livestock, bark or root for medicine, and so forth), any farmer within the community can benefit from it. In other words, farmers who have not protected new stems or do not have the trees they need in their cropland, can collect what they need from the trees in someone else's cropland but this has to be done with permission from the owner of the cropland, and taking care not to damage the tree. Respondents believe that asking permission from the owner serves to honor the person for caring for and managing the tree and is a way to strengthen relationships within the community. However, even if non-compliance with this procedure is considered theft, some people do not always ask permission before entering someone else's cropland to collect tree products. Saaga, a farmer from Boala explained that he once had an altercation with a woman, because she collected medicinal products from the roots of one of his trees without asking him beforehand. Later, he realized that she cut the roots inappropriately, resulting in the death of the tree. Since then, he feels offended every time he sees the woman. This case is not isolated and shows how trees can also be a source of tensions between community members. Fortunately, these tensions are usually solved within the community.

4.4 Legal Regulations

Farmer managed natural regeneration is a farmer-led initiative, however, the government of Burkina Faso has taken measures to protect trees including those managed by farmers in their croplands. In fact, in 2011 the National Assembly voted an update to the *Forest Code* to protect and enhance forests or forestland, wildlife, and fisheries through sustainable management (Burkina Faso Assemblée Nationale 2011, 2). Any forest land, restoration sites, fenced-off reforestation areas, agroforestry parks, and trees outside forests are subject to the forest regime defined in this law. The *Forest Code* defines agroforestry parks as “ecosystems characterized by omnipresence of a woody stratum dominating in height a formation of herbaceous plant which can be agricultural fields” (Burkina Faso Assemblée Nationale 2011, 4). This definition includes FMNR, legally preventing farmers from cutting trees or branches without prior authorization. Any forest product (including products from agroforestry parks) obtained fraudulently is forfeited without prejudice to the application of criminal sanctions applicable, and the means used to commit the offense are seized as conservatory measure until settlement of the dispute (Burkina Faso Assemblée Nationale 2011, 47). In addition, those who cut trees without authorization are punishable with jail time of six months to three years and a fine of 10,000 FCFA (about 16.5 USD) up to 2,000,000 FCFA (about 3,300 USD) or one of these two sentences only. This sentence can be doubled if a person is charged twice with the same infraction (Burkina Faso Assemblée Nationale 2011, 48).

Although the government has taken steps to protect trees in croplands, the fact remains that in the traditional Mossi chiefdom, each village has its own chiefs responsible for the people, the land, and the activities on the land. On one hand, the village chief is responsible for protecting the people in the village and ensuring their well-being. On the other hand, the “Tengsoaba” or “chief of the land” is responsible for the land especially lands that belong to the community. He is responsible for performing rites to ensure peace and productivity in the village, ensuring a sustainable and equitable management of reserves, allocating land to foreigners, monitoring the proper use of natural resources, and arbitrating settlement of land disputes within the community or with neighboring villages (FAO 2020a). His duties, however, do not include land belonging to natural or legal persons (landowners). These lands are entirely managed by the landowners and are generally passed from generation to generation. Nonetheless, if the government or the village chief needs someone's land, the "Tengsoaba" is responsible for negotiating with the landowner. Additionally, when a landowner sells or donates a land lot, the "Tengsoaba" must be informed of the new landowner identity. In summary one can become a landowner by: receiving land as part of a heritage, receiving temporally or definitively land from the "chief of the land" (he is prohibited from selling land), and receiving or buying (temporally or definitively) land from landowners. Landowners have exclusive rights to their land and are free to exclude others from using or benefiting from products of their land, unless otherwise specified by the "Tengsoaba" when acquiring the land. These principles apply to croplands.

4.5 Summary of the Results

Farmer managed natural regeneration is represented at different stages in the Nord Plateau Mossi, ranging from new stems to growing and mature FMNR fields (Image 15). This chapter used ANOVA to analyze soil content in carbon, organic matter, nitrogen, potential of hydrogen, total exchangeable base cations, cation-exchange capacity, and base saturation from soil samples collected in the study area. The results show that soil content in carbon, organic matter, and nitrogen were higher within the tree canopy compared to 15 m and 30 m outside the tree canopy regardless of the village or tree species. FMNR increased soil fertility by increasing soil carbon, organic matter, and nitrogen. Additionally, increased organic matter and nitrogen improves water holding capacity and infiltration, moisture, drainage, microbial activities, root penetration, and plant growth (Allison 1973, 315- 461). Soil carbon increases crop yields in three ways: by increasing the amount of water available for plant use in the soil, improving nutrient supply, and enhancing soil physical properties (Lal 2006, 198). The analysis of variance also revealed that the mean values of total exchangeable base cations and cation-exchange capacity are only significantly different from one village to another. In terms of potential of hydrogen and base saturation, ANOVA identified no significant difference based on site, type, or distance.

This chapter also highlighted the importance of farmer managed natural regeneration in the obtaining of firewood for farmer households. FMNR provides bundles of firewood from tree branches. Additionally, trees contribute to increasing household income, provide vegetables, cooking oil, and fruits (Image 16), as well as medicinal products, poles for construction, and wood for granaries. FMNR can also be source of tensions between community members.

Image 15. FMNR illustration in Nord Plateau Mossi

Image 16. Examples of fruits consumed

CHAPTER 5: CONCLUSION

Previous research found several benefits of farmer managed natural regeneration for farmers. Among those benefits, trees help maintain and improve soil fertility, by improving soil organic matter and fixing nitrogen from the air into the soil. They also provide poles for construction and reduce wind speed. In addition, trees produce fodder for livestock, provide medicinal products, firewood, and fruits that can be consumed at the household level or be sold to generate cash.

This study used human, physical, and technical geography to examine the biophysical and socioeconomic impacts of farmer managed natural regeneration in the Nord Plateau Mossi of Burkina Faso. I wanted to learn how FMNR affects soil productivity, household access to a variety of foods, and farmers' income because few studies show the impacts of FMNR on farmers' lives. The study addressed several questions, including determining the changes induced or resulting from FMNR on household income in the Nord Plateau Mossi, determining the impacts of FMNR on household dietary diversity and in the obtaining of firewood, and identifying the changes generated by FMNR in soil fertility. To reach my objectives, I used focus groups to interview farmers in the study area to learn their motivations for choosing whether to adopt FMNR, and identify the income changes induced by FMNR. Respondents stated for example that they use wood as fences, as well as for other purposes. The Food and Agriculture Organization of the United Nations household dietary diversity survey provided a way to determine the nutritional adequacy of farm households in the study area. Additionally, I collected soil samples under and away from trees to assess their impact on soil fertility.

Respondents from focus groups suggested that FMNR started before the droughts of the 1970s the Nord Plateau Mossi. When asked why they protect trees, some respondents stated that trees are valuable features, and are essential for human survival. Others, such as the chief of Kaoukouagin, said that farmers in his village protect trees to provide a better environment for their children and grandchildren, because trees provide important services to people. Indeed, FMNR offers multiple benefits. The savings made from not needing to purchase firewood and the sales of shea nuts, FMNR contributes 81 to 184 USD to household income per year. Additionally, FMNR contributed to household income in ways that were not measured in the focus group. These ways include the cash sale of other tree products such as fodder for livestock and fruits (including from *Vitellaria paradoxa* and *Tamarindus indica*).

The results of this thesis demonstrate that trees increase soil fertility by increasing the amount of carbon, organic matter, and nitrogen in the soil therefore improving supply of nutrients for plants, as well as soil's water holding capacity, incrustation, moisture, drainage, microbial activities, and root penetration (Lal 2006, 198; Allison 1973, 315). These are likely to increase crop yields and make farmer households less vulnerable to food insecurity. FMNR also facilitates obtaining firewood by making trees, whose branches are used for this purpose, available to households. Farmer managed natural regeneration also improves household access to a variety of foods because trees provide leaves (used as vegetables), cooking oil, and fruits for their consumption. This represents 3 of the 12 food groups considered important by the United Nations Food and Agriculture

Organization. FMNR also provides medicinal products, reduces wind speed, and keeps the soil moist. Additionally, tree leaves are used to fertilize croplands, make compost, and protect croplands from sunlight. Tree branches are used as poles for construction, wood for granaries, and fences. Despite its multiple benefits, FMNR can also lead to tensions.

In terms of limitations, I was not able to learn the percentage of farm household income that comes from trees, because of a lack of income and crop production data for farm households within the villages. I was also unable to select and collect data on more than the five villages used in this thesis because of terrorist movements in Burkina Faso. As mentioned earlier, this research collected data from focus groups, surveys, and soil samples in five villages within the Nord Plateau Mossi. These villages were selected because representatives from NGOs were available to help approach farmers and give safe passage through the villages. In addition, data had to be collected within a few hours, with a limited number of days to spend in each village. We were not allowed to spend the night in the villages and had to leave an hour or two before evening, whether we were finished or not. These reasons surely affected the ability of this research to provide more in-depth analysis of the biophysical and socioeconomic impacts of FMNR in the study area. Specifically, this study failed to compare the impacts of trees on soil fertility, household income, the obtaining of firewood, and motivations in choosing whether to adopt FMNR within villages with FMNR and villages without FMNR. In addition, the analysis of the data collected failed to provide any significant result for soil’s composition in pH and base saturation in the study area.

Additionally, the literature acknowledged *Faidherbia albida* as a nitrogen fixing tree; however, this study failed to identify a significant difference between nitrogen content in the soil under *Faidherbia albida* trees and other tree species. This can be explained by the period in which the samples were taken. The samples were collected in July, which is during the rainy season in Burkina Faso. Most trees used in this study for soil sampling grow, are fully leafed out, and bear fruits during this season. However, this is not the case with *Faidherbia albida*, which is dormant during the rainy season. The latter grows and is in leaf during the dry season, implying reduced activity during rainy seasons. Its reverse phenology is unique among trees in sub-Sahara Africa.

Future research can strengthen the findings from this study by incorporating data from villages without FMNR. The data collected can also be enhanced by collecting data from both rural and urban areas. This will likely show different facets of the impact of FMNR on farmers lives. Additionally, some authors situated the expansion of FMNR in sub-Sahara Africa after the drought of the 1970s and 1980s; however, focus groups from this study revealed that farmers in the Nord Plateau Mossi were using FMNR before the 1970s. It is then important that future research focuses on dating the origins and expansion of FMNR, as well as addressing whether FMNR is becoming more common, stable, or less common in the study area. Future research can also strengthen this study by investigating the relationship between firewood consumption and population growth and how it might affect FMNR.

Sustainable development aims to meet the needs of the current generation without exposing future generations to a lack of resources for their own needs. Farmer managed natural regeneration is a land restoration and management technique that started before the 1970s in the Nord Plateau Mossi. It is also a solution to the increased demands in Africa for agriculture and benefits from the natural environment such as reducing wind speed, protecting the soil from sunrays, and so forth. By protecting trees on their croplands, farmers have gained access to a larger variety of food and more marketable farm products to increase their income. Farmer managed natural regeneration mixes agriculture and environmental protection in a sustainable and beneficial way for humans and nature. The results of this thesis constitute an addition to the existing literature on FMNR and its impacts in sub-Sahara Africa. The results are important, because they demonstrate an improvement induced by FMNR in farmers' lives which, in turn, can be used to educate other farmers who may be willing to adopt FMNR to restore their degraded croplands, and thus contribute to the fight against poverty and hunger in Burkina Faso.

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APPENDICES

APPENDICE A: Consent form

CONSENT TO BE PART OF THE RESEARCH STUDY

INFORMATION ABOUT THIS FORM

You may be eligible to take part in a research study. This form gives you important information about the study. It describes the purpose of the study, and the risks and possible benefits of participating in the study.

Please take time to review this information carefully. After you have finished, you should talk to the researchers about the study and ask them any questions you have. You may also wish to talk to others (for example, your friends, or family) about your participation in this study. If you decide to take part in the study, you will be asked to sign this form. Before you sign this form, be sure you understand what the study is about, including the risks and possible benefits to you.

1. **GENERAL INFORMATION ABOUT THIS STUDY AND THE RESEARCHERS**

The title of the study is: Biophysical and Economic Impacts of farmer managed natural regeneration in the Province of Bam in Burkina Faso and is directed by Basnewende Brice Fulgence Zoungrana, master's student at South Dakota State University.

2. **PURPOSE OF THIS STUDY**

As a researcher, I am looking at farmer managed natural regeneration (FMNR) impacts in the province of Bam in Burkina Faso, because I want to know how FMNR affects soil productivity, household access to a variety of foods, and farmers' income.

3. INFORMATION ABOUT STUDY PARTICIPANTS

Taking part in this study is completely voluntary. You do not have to participate if you don't want to. You may also leave the study at any time. If you leave the study before it is finished, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled.

Any farmer (male or female) who is at least 23 years old is potentially eligible to take part in this study. Overall, about 120 farmers are expected to take part in the study.

4. INFORMATION ABOUT STUDY PARTICIPATION

In this study, participants will gather in a focus group format to discuss the impacts of farmer managed natural regeneration (FMNR). The focus group will take approximately an hour and participants will be able to leave when the researcher closes the discussions. Subjects may also leave the focus group at any time. They do not need to stay until the end.

5. INFORMATION ABOUT RISKS AND BENEFITS

The expected contribution of the participants are ideas, experiences, and opinions about adopting FMNR or not. Therefore, disagreements and discords might result from the discussion, and possibly lead to social tensions. The researcher will play the role of moderator and will strive to smooth the debate and avoid tensions between participants. You will not receive any personal benefits from being in this study, but the researcher will tell you if he learns of important new information that may change your point of view on FMNR and possibly benefit you.

6. CONFIDENTIALITY OF SUBJECT RECORDS AND AUTHORIZATION TO RELEASE YOUR PROTECTED INFORMATION

Signing this form gives the researchers your permission to obtain, use, and share information about you for this study, and is required for you to take part in the study. Information about you may be exclusively viewed by the researcher and academic advisor.

There are many reasons why information about you may be used or seen by the researchers or academic advisor during or after this study. Examples include:

- The researchers may need the information to make sure you can take part in the study.
- Academic advisor may need the information to:
    - ✓ Make sure the study is done safely and properly
    - ✓ Learn more about side effects
    - ✓ Analyze the results of the study

The results of this study could be published in an article, but would not include any information that would let others know who you are. However, you may cancel your permission as well at any time by writing to the researcher listed in the Section below. All recordings will be converted into a digital file and stored on the researcher's personal computer and a flash drive backup to ensure confidentiality.

With your permission, I would like to record your participation so that I can make an accurate transcript. Once I have made the transcript, I will erase the recordings. Your name will not be in the transcript or my notes. You will not be identified in any report or publication of this study. Even though we will tell all participants in the study that the comments made during the focus group should be kept confidential, it is possible that participants may repeat comments outside the group.

The information that you provide in the study will be handled confidentially. However, there may be circumstances where this information must be released or shared as required by law. The SDSU Institutional Review Board may review the research records for monitoring purposes. Identifiers may be removed and your information may be used for future research or shared with another researcher for future research without additional consent.

7. CONTACT INFORMATION

In case of inquiries or concerns of any kind regarding the study or your permission, you may contact Basnewende Brice Fulgence Zoungrana at:

- ✓ bbrice.zoungrana@gmail.com
- ✓ Basnewende.zoungrana@jacks.sdstate.edu
- ✓ +1 605 839 9195
- ✓ South Dakota State University, Wecota Hall 109, Geography-Box 0506, University Station, Brookings, SD 57007, USA.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact SDSU's Research Integrity and Compliance Officer at 605-688-5051 or sdsu.irb@sdstate.edu.

8. RECORD OF INFORMATION PROVIDED

Your signature in the following section means that you have read and accepted this consent form and that you receive a copy upon request.

9. CONSENT/ASSENT TO PARTICIPATE IN THE RESEARCH STUDY

I understand the information printed on this form. I have discussed this study, its risks and potential benefits, and my other choices with {Basnewende Brice Fulgence Zoungrana}. My questions so far have been answered. I understand that if I have more questions or concerns about the study or my participation as a research subject, I may contact one of the people listed in Section 7 (above). I understand that I will receive a copy of this form at the time I sign it or later upon request. I understand that if my ability to consent or assent for myself changes, either I or my legal representative may be asked to re-consent prior to my continued participation in this study.

Legal Name:

____

Signature:

____

_

Date of Signature (mm/dd/yy): _________________________

APPENDICE B: Interview schedule

Introduction

This interview will evaluate the biophysical and economic impacts farmer managed natural regeneration, and is directed by Basnewende Brice Fulgence Zoungrana, Masters Student at South Dakota State University. Participation in this study is voluntary, and participants may leave at any time during the interview.

Questions

1. I see that there are trees in your cultivated fields. Were they planted, or did they sprout naturally?
2. When you were young, during the time of Sangoulé Lamizana (1966-80), were there trees in the fields? Were there more, or less, than now? Why?
3. Describe the vegetation in the surrounding bushland (non-farm vegetation), when you were young, compared to now.
4. Are you protecting trees in the farmlands? If yes, when did you start to protect them? (if no go to question 16)
5. Why have you decided to revegetate your farmland by protecting the existing trees?
6. What do you think are the benefits of trees within farmlands? Is there a species of tree that benefits you more than others?
7. Have you had an improvement in your income since you started to revegetate your farmland? How much?
8. Have the trees improved your crop production? If yes, how? And how much?
9. Have the trees improved your soils? How?

10. Have the trees improved your access to firewood? Do you sell the firewood for cash? If yes, at what percentage does it contribute to your revenue?
11. Are there other products from the trees that you use? Do you sell other products (pods, fodder) for cash?
12. Are you eating more or better now compare to when you were young? why? How does this connect to having field trees?
13. Were you able to feed more animals with the presence of trees in your farmland?
14. What else are you using the trees for?
15. Who owns the trees (you, the government, or the Forest Service)? When you were young, who owned the trees?
16. Do you have the right or not to freely cut trees down, cut firewood, or use them for food? Why? Has that changed since the time of Sangoulé Lamizana?
17. Will you keep protecting trees in your croplands?

APPENDICE C: Survey Form

Participant Survey Form

Background Information

This survey is designed to assess household dietary diversity, collect data for the completion of the Master thesis of Basnewende Brice Fulgence Zoungrana from South Dakota State University. "Dietary diversity is a qualitative measure of food consumption that reflects household access to a variety of foods, and is also a proxy for nutrient adequacy of the diet of individuals" (FAO, 2011). By signing, the participant undertakes to provide his information as part of this research.

Interviewee Information

Name : **Location:** **Signature:**

Question #1: Describe in detail the type of foods (i.e: rice, potato, fruits, juice drink, spices, tea…) that you ate or drank yesterday for **breakfast**, whether at home or outside the home.

Notes:

Question #2: Describe in detail the type of foods (i.e: rice, patato, fruits, juice drink, species, tea…) that you ate or drank yesterday for **lunch**, whether at home or outside the home.

Notes :

Question #3: Describe in detail the type of foods (i.e: rice, patato, fruits, juice drink, species, tea…) that you ate or drank yesterday for **dinner**, whether at home or outside the home.

Notes:

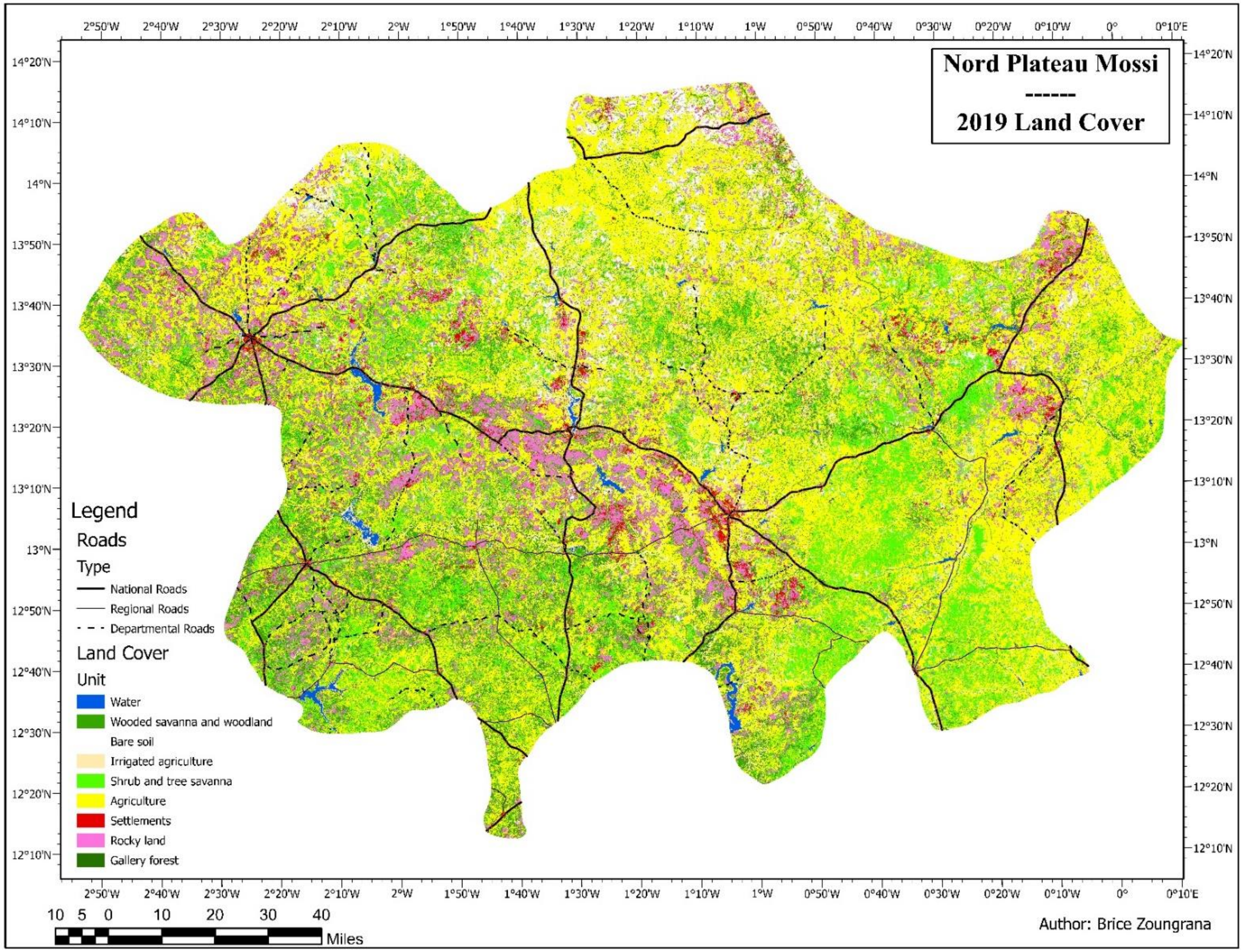
Question #4: Describe in detail any **snack** that you ate or drank yesterday at any time during the day or night, whether at home or outside the home.

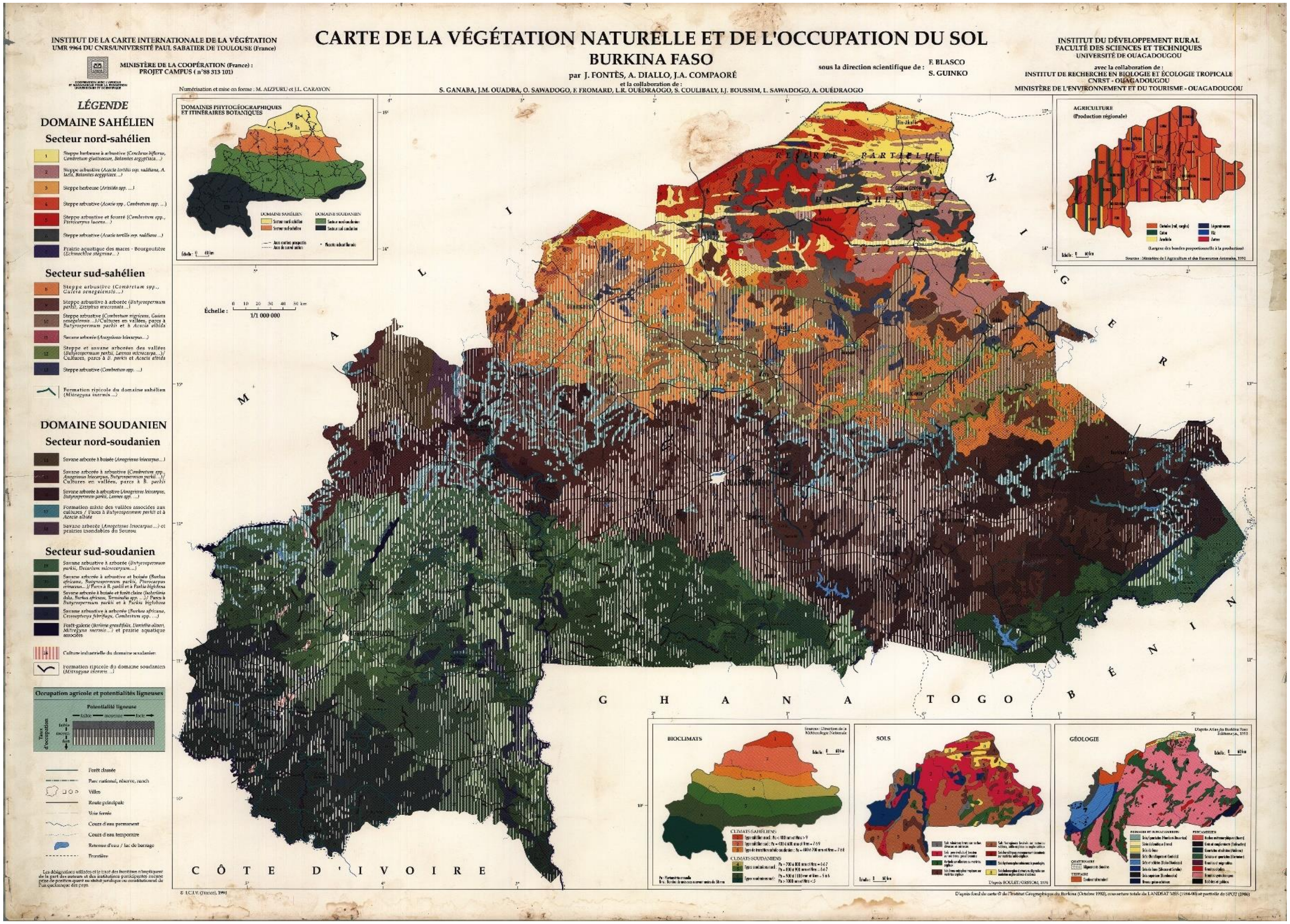
Notes:

APPENDICE D: Soil Analysis Data

N° Lab	Site	Tree specie	Distance	C (%)	OM (%)	N (%)	pH	Ca++ (meq/100)	Mg++ (meq/100)	K+ (meq/100)	Na+ (meq/100)	TEBC (meq/100)	CEC (meq/100)	BS (%)
1297	Boala	*Vitellaria paradoxa*	Under tree	0.828	1.427586	0.08	5.6	1.77	0.13	0.51	0.06	2.47	4.28	58
1298			15 m	0.211	0.363793	0.025	5.77	1.84	0.13	0.43	0.06	2.46	4.47	55
1299			30 m	0.479	0.825862	0.053	5.1	1.96	0.13	0.43	0.08	2.6	4.16	63
1300		*Faidherbia albida*	Under tree	0.617	1.063793	0.08	5.95	2.54	0.09	0.39	0.06	3.08	4.5	68
1301			15 m	0.592	1.02069	0.053	5.78	2.66	0.08	0.39	0.06	3.19	4.71	68
1302			30 m	0.633	1.091379	0.061	5.97	1.76	0.05	0.39	0.06	2.26	4.4	51
1303		Clear area	0 m	0.82	1.413793	0.075	5.07	2.63	0.27	0.31	0.06	3.27	4.22	77
1304			15 m	0.69	1.189655	0.08	5.73	2.14	0.21	0.31	0.08	2.74	4.5	61
1305	Kaoukouagin	*Balanites aegyptiaca*	Under tree	0.658	1.134483	0.07	5.92	7.93	1.11	0.31	0.06	9.41	16.45	57
1306			15 m	0.536	0.924138	0.053	5.96	8.06	1.02	0.31	0.06	9.45	15.47	61
1307			30 m	0.585	1.008621	0.056	6.03	5.99	0.73	0.39	0.08	7.19	10.15	71
1308		Clear area	0 m	0.747	1.287931	0.07	5.92	3.21	0.32	0.31	0.06	3.9	5.84	67
1309			15 m	0.527	0.908621	0.061	5.66	4.72	0.38	0.39	0.06	5.55	7.7	72
1310		*Faidherbia albida*	Under tree	0.804	1.386207	0.084	5.86	7.84	0.62	0.39	0.08	8.93	13.04	68
1311			15 m	0.56	0.965517	0.053	6.11	6.8	0.81	0.39	0.08	8.08	12.89	63
1312			30 m	0.552	0.951724	0.061	6.24	6.78	0.8	0.43	0.06	8.07	13.36	60
1313	Mogodin	*Acacia nilotica*	Under tree	0.983	1.694828	0.098	5.74	3.92	0.14	0.7	0.06	4.82	6.74	72
1314			15 m	0.772	1.331034	0.08	5.15	3.22	0.1	0.82	0.06	4.2	5.45	77
1315			30 m	0.576	0.993103	0.066	5.5	4.04	0.1	0.39	0.08	4.61	6.23	74
1316		*Vitellaria paradoxa*	Under tree	0.34	0.586207	0.038	5.23	1.65	0.15	0.39	0.06	2.25	3.45	65
1317			15 m	0.374	0.644828	0.043	6.01	1.47	0.09	0.43	0.06	2.05	2.85	72
1318			30 m	0.349	0.601724	0.038	5.97	1.02	0.09	0.39	0.06	1.56	2.82	55
1319		Clear area	0 m	0.357	0.615517	0.034	5.03	2.17	0.13	0.63	0.08	3.01	4.11	73
1320			15 m	0.439	0.756897	0.053	5.47	2.05	0.22	0.58	0.06	2.91	3.96	73
1321	Safi	*Lannea microcarpa*	Under tree	0.811	1.398276	0.08	5.45	2.75	0.1	0.43	0.06	3.34	4.72	71
1322			15 m	0.649	1.118966	0.061	5.41	2.36	0.04	0.39	0.06	2.85	4.35	66
1323			30 m	0.406	0.7	0.043	5.8	0.68	0.05	0.43	0.08	1.24	2.33	53
1324		*Faidherbia albida*	Under tree	0.389	0.67069	0.048	5.17	1.3	0.06	0.39	0.06	1.81	2.85	64
1325			15 m	0.447	0.77069	0.053	6.56	0.43	0.05	0.39	0.08	0.95	1.86	51
1326			30 m	0.389	0.67069	0.043	5.78	0.74	0.06	0.43	0.08	1.31	2.26	58
1327		Clear area	0 m	0.488	0.841379	0.053	5.51	1.39	0.1	0.43	0.06	1.98	3.3	60
1328			15 m	0.389	0.67069	0.043	5.58	0.64	0.06	0.43	0.06	1.19	1.84	65
1329	Tema	*Faidherbia albida*	Under tree	0.966	1.665517	0.102	5.62	1.24	0.17	0.89	0.08	2.38	3.42	70
1330			15 m	0.641	1.105172	0.066	5.76	1.66	0.1	0.43	0.08	2.27	3.68	62
1331			30 m	0.633	1.091379	0.07	5.35	1.89	0.15	0.39	0.06	2.49	3.4	73
1332		*Adansonia digitata*	Under tree	0.52	0.896552	0.053	5.76	0.87	0.1	0.39	0.08	1.44	2.33	62
1333			15 m	0.495	0.853448	0.056	5.34	0.82	0.09	0.43	0.06	1.4	2.28	61
1334			30 m	0.316	0.544828	0.034	5.79	0.93	0.09	0.51	0.06	1.59	2.96	54
1335		Clear area	0 m	0.893	1.539655	0.107	5.64	0.86	0.07	0.58	0.06	1.57	2.52	62
1336			15 m	1.039	1.791379	0.102	5.7	1.22	0.08	0.51	0.06	1.87	2.93	64

APPENDICE E: Land Cover Maps





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PROJET CAMPUS (n°88 313 101)
CARTE DE LA VÉGÉTATION NATURELLE ET DE L'OCCUPATION DU SOL
BURKINA FASO
par J. FONTÈS, A. DIALLO, J.A. COMPAORÉ
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et la collaboration de :
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avec la collaboration de :
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CNRST - OUAGADOUGOU
MINISTÈRE DE L'ENVIRONNEMENT ET DU TOURISME - OUAGADOUGOU
LÉGENDE
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Secteur sud-sahélien
DOMAINE SOUDANIEN
Secteur nord-soudanien
Secteur sud-soudanien
Occupation agricole et potentialités ligneuses
DOMAINES PHYTOGÉOGRAPHIQUES ET ITINÉRAIRES BOTANIQUES
AGRICULTURE
(Production régionale)
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N I G E R
G H A N A
T O G O
B É N I N
C Ô T E D'I V O I R E
BIOCLIMATS
SOLS
GÉOLOGIE

APPENDICE F: Photos of trees used for sampling



APPENDICE G: Farmer managed natural regeneration new stems

APPENDICE H: Photos with farmers

APPENDICE I: Soil sampling